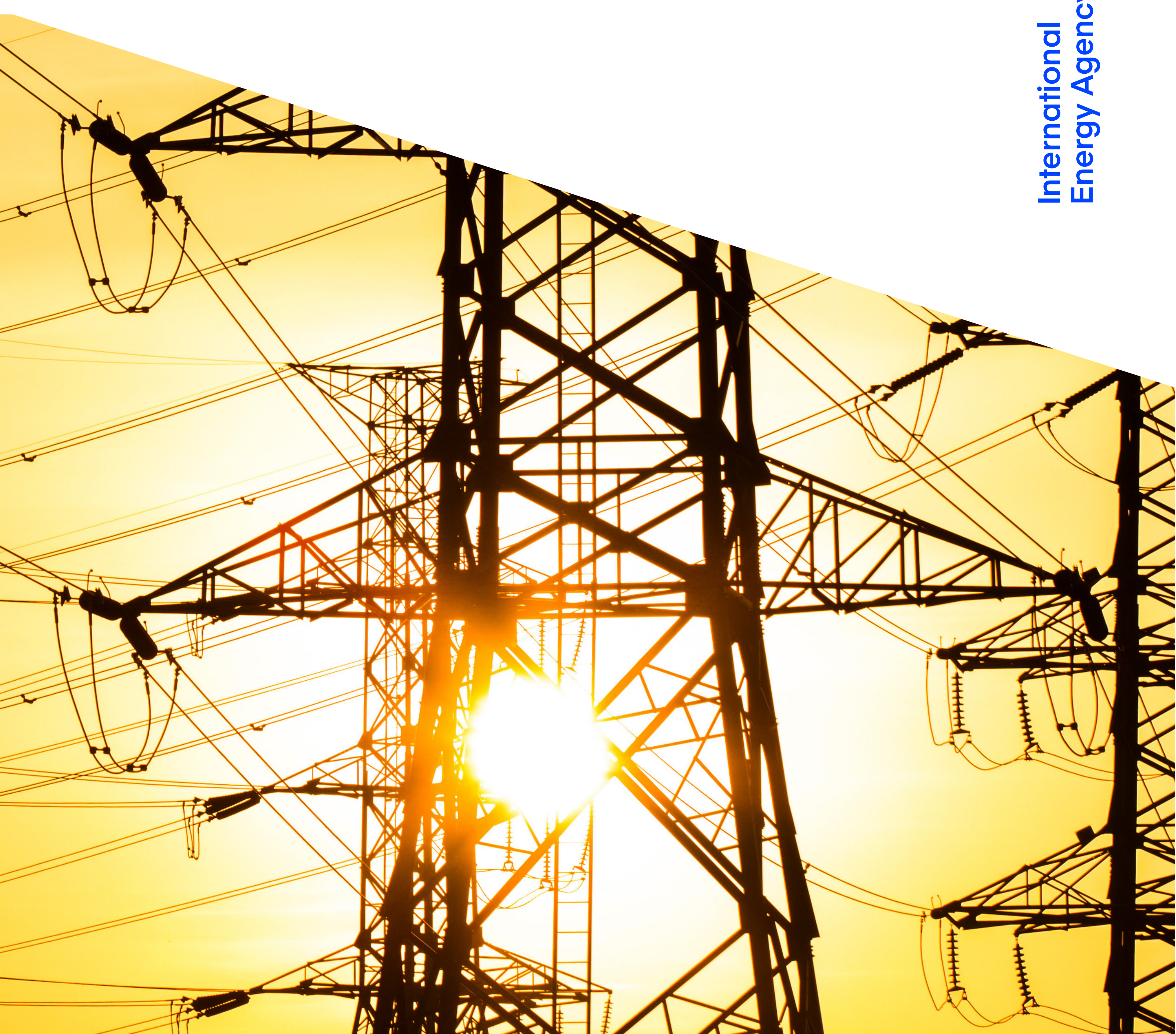
Electricity Mid-Year Update

July 2024

International Energy Agency



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Abstract

Despite the enduring impacts of the global energy crisis, growth in electricity demand has remained robust in the first half of 2024 due to solid economic activity in many regions, intense heatwaves and continued electrification.

This mid-year update, which follows the Electricity 2024 report published in January, explores these trends and their implications for 2025. It features the latest data for 2023 and new 2024 and 2025 forecasts for global electricity demand, supply by fuel type, and carbon dioxide (CO_2) emissions from the power sector. It also analyses the latest developments in major markets, including China, the United States, the European Union and India.

The report includes a special focus on electricity demand trends in Europe and their drivers, as well as recent developments related to the global data centre sector and its electricity consumption. In addition, this update provides a comprehensive analysis of the increasing prevalence of negative electricity prices in various power markets worldwide.

Acknowledgements, contributors and credits

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Executive summary

In 2024 and 2025, the world's electricity demand is set to grow at the fastest pace since its post-Covid rebound

Over the 2024-2025 forecast period of this report, global electricity consumption is expected to increase at the fastest pace in years, fuelled by robust economic growth, intense heatwaves and continued electrification worldwide. The 4% growth expected for 2024 is the highest since 2007, with the exceptions of the sharp rebounds in 2010 after the global financial crisis and in 2021 following the Covid-induced demand collapse. The growth is driven by strong electricity demand in multiple regions and countries, especially in the People's Republic of China (hereafter, "China"), India and the United States. We expect this demand trend to continue in 2025, with growth also at 4%. In both 2024 and 2025, the rise in the world's electricity use is projected to be significantly higher than global GDP growth of 3.2%. In 2022 and 2023, electricity demand grew more slowly than GDP.

Electricity demand in China is forecast to increase by 6.5% in 2024, similar to its average rate between 2016 and 2019. This still strong annual growth represents a modest slowdown from 7% in 2023 amid the ongoing restructuring of the Chinese economy. Electricity consumption in 2024 and 2025 is expected to be driven by robust activity in the services industries and various industrial sectors, including a rapid rise in solar PV, electric vehicle (EV) and battery production, and the electricity-intensive processing of related materials. Continued expansion of 5G networks and data centres as well as strong EV uptake in the domestic market are also contributing factors. Over the last three years, China has been adding electricity demand roughly equivalent to that of Germany each year, on average, and this trend is expected to continue through 2025, with growth forecast at 6.2%.

India, the fastest growing major economy in the world, is forecast to post an 8% rise in electricity consumption in 2024, matching the rapid growth it saw in 2023. This is supported by strong GDP growth and increased cooling demand due to long and intense heatwaves. In the first half of 2024, the country grappled with heatwaves of record duration, with peak load reaching a new high and putting exceptional strains on power systems. Assuming a return to average weather conditions, we expect electricity demand growth in India to ease moderately to 6.8% in 2025.

Electricity demand in the United States is set to rebound significantly in 2024, increasing by 3% year-on-year. The stronger growth rate is due, in part, to the comparison with 2023 when demand declined by 1.6% amid mild weather.

Electricity consumption is boosted by an improved economic outlook as well as rising demand for air conditioning amid severe heatwaves and the surge in data centre expansions. Demand is forecast to rise by 1.9% in 2025.

Electricity demand in the European Union is expected to increase by 1.7% in 2024 as economic difficulties ease, but uncertainty over the pace of growth remains. EU electricity consumption had contracted over the two previous years, with the decline in output from energy-intensive industries an important driver. Signs of a recovery in EU electricity demand emerged starting in the fourth quarter of 2023. Growth gained further traction during the first half of 2024 as energy prices stabilised and various industries that had previously curtailed operations restarted. Nevertheless, while coming down from previous highs, energy prices in Europe are still elevated compared with pre-Covid levels. This, combined with a moderately sluggish macroeconomic outlook, continues to weigh on some industries and raises uncertainties over the pace of the demand recovery.

The rise of artificial intelligence (AI) has put the electricity consumption of data centres in focus, making better stocktaking more important than ever. In many regions, historical estimates of data centres' electricity consumption are hampered by a lack of reliable data. At the same time, future projections include a very wide range of uncertainties related to the pace of deployment, the diverse and expanding applications of AI, and the potential for energy efficiency improvements. Expanding and improving the collection of electricity demand data from the sector will be crucial to identify past developments correctly and to understand future trends better. The International Energy Agency (IEA) has been a frontrunner in studying the links between the energy sector and digitalisation. To provide more insight into the topic, the IEA will be hosting the Global Conference on Energy and AI in December 2024, bringing together governments, industry, researchers and other stakeholders.

Heatwaves continue to strain power systems worldwide

Many regions struggled with intense heatwaves in the first half of 2024, which elevated electricity demand and strained power grids. May 2024 was the hottest month since global records began and the 12th consecutive month of record-high temperatures. India, Mexico, Pakistan, the United States, Viet Nam, and many other countries saw severe heatwaves with surging peak loads due to the increased need for cooling. As more households begin to purchase air conditioners (ACs), the impact will grow substantially, particularly in emerging economies where the proportion of households with ACs is currently much lower compared with advanced economies with comparable climates. Implementing higher efficiency standards for air conditioning will be crucial to mitigate the impact of increased cooling demand on power systems. The expansion and reinforcement of power grids will also be very important to ensure reliability.

Clean energy sources will set new records through 2025

Despite the sharp rise in electricity use, solar PV alone is expected to meet roughly half of the growth in global electricity demand to 2025. Together with wind power generation, it will make up almost 75% of the increase.

Global electricity generation from solar PV and wind is expected to surpass that from hydropower in 2024. This follows a massive 33% year-on-year increase in global solar PV generation and sustained growth in wind generation of 10%. The global energy transition is set to achieve another significant milestone by 2025, with total renewable generation poised to overtake coal-fired electricity output. The share of renewables in global electricity supply rose to 30% in 2023 and is projected to climb further to 35% in 2025.

In the European Union, wind and solar PV generation is set to exceed fossil-fired output in 2024. Wind and solar PV's combined share in total electricity supply is forecast to rise from 26% in 2023 to 30% in 2024, and to 33% in 2025. The primary driver is the rapid growth of solar PV, led by reduced prices of solar modules combined with strong policy support. The share of all renewable energies in total generation is expected to reach 50% in 2024.

Global nuclear generation is on track to reach a new high in 2025, surpassing its previous record in 2021. Nuclear generation is forecast to rise globally by 1.6% in 2024, and by 3.5% in 2025. This growth is supported by a steady increase in output by the French nuclear power fleet as maintenance works are completed, by the restarting of reactors in Japan, and by new reactors coming online in various markets, including China, India, Korea and Europe.

Power sector emissions are plateauing, with a slight increase in 2024 followed by a decline in 2025

Coal-fired output is set to remain resilient in 2024 due to strong electricity demand growth, hindering a decline in global power sector CO_2 emissions. Despite the rapid growth of renewables, the brisk increase in electricity consumption, especially in China and India, is resulting in the use of more coal-fired generation to meet demand. Global coal-fired output is expected to increase by less than 1% in 2024, but this is highly dependent on hydropower trends, especially in China. Chinese hydropower output rebounded strongly in the first half of 2024 from its 2023 low, and a further improvement in hydropower trends in the second half of the year could curb coal-fired power generation and reduce global power sector emissions. Global natural gas-fired output is forecast to grow on average by around 1% over the 2024-2025 period**.** Significant declines in Europe are set to be offset by increases in Asia, amid rising LNG imports, and in the Middle East, driven by switching from oil-fired to gas-fired generation.

Global CO_2 emissions from electricity generation are set to remain broadly on a plateau through 2025. The slight increase in power sector emissions in 2024 is expected to be followed by a decrease of less than 1% in 2025. This will be driven by a modest fall in coal-fired output due to further expansion of clean energy sources and the continued decline in oil-fired generation. While extreme weather conditions such as heatwaves and droughts, as well as economic shocks or changes in government policies, can cause an uptick in emissions in individual years, the structural trend of clean energy sources constraining fossil fuels will remain robust.

The United States is forecast to see an uptick in power sector CO_2 emissions in 2024 before a decline in 2025. The United States is one of the few advanced economies that will see its power sector CO_2 emissions rise in 2024, though they will still be almost 30% lower than a decade earlier. The 2024 increase follows a sharp decline of 8% in 2023, when there was a massive 20% drop in coal-fired power generation due to strong competition from very low natural gas prices and lower electricity demand amid mild weather. In 2024, US coal-fired generation is expected to grow by around 2% and natural gas by 1.5%, leading to an increase in emissions. This is driven by a significant rebound in US electricity demand growth after the decline in 2023 and by the limited scope for further coal-to-gas switching, given the current fuel price dynamics. Nevertheless, these trends will be highly dependent on further developments in market prices for natural gas and weather trends in the second half of 2024.

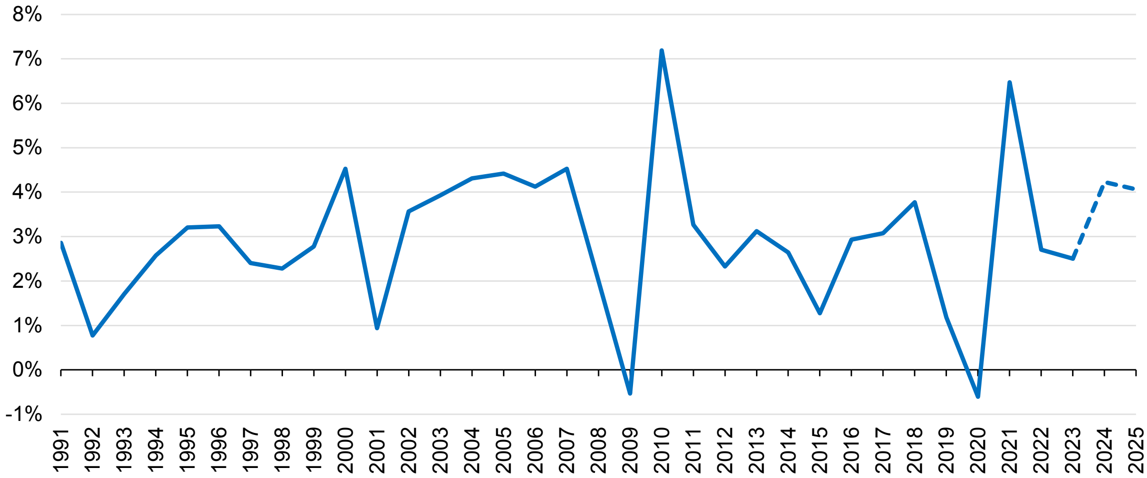
Rising frequency of negative electricity prices signals the urgent need to increase system flexibility

There has been a significant increase in 2024 in the frequency of negative wholesale price events in numerous power markets. In the first half of the year, the share of negatively priced hours in Southern California was above 20%, more than tripling from a year before. In some markets, such as South Australia, prices have been negative for about 20% of the time since 2023. Negative prices occur because generation is not flexible enough due to technical, economic, contractual or regulatory reasons. They indicate that the demand side is not sufficiently responsive to prices and that there is not enough storage available. Rising frequency of negative prices sends an urgent signal that greater flexibility of supply and demand is needed. The appropriate regulatory frameworks and market designs will be important to allow for an uptake in flexibility solutions such as demand response and storage.

Demand: Global electricity use set to grow much faster in 2024-2025

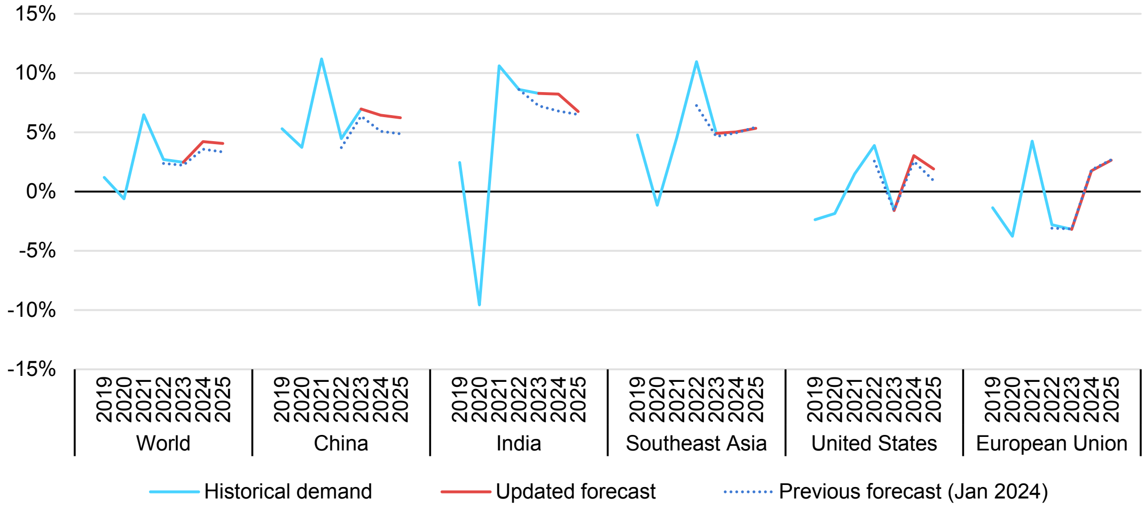
Economic headwinds, combined with a slowdown in manufacturing activity and mild weather in key regions, tempered global electricity demand in 2023 to an average annual growth rate of 2.5%, down from 2.7% in 2022. However, world electricity consumption is forecast to increase at a much higher pace in 2024, with growth set to reach 4% – the highest rate the world has seen since 2007, barring the exceptional rebounds in 2010 after the financial crisis and in 2021 following the Covid-19 pandemic demand collapse.

Year-on-year percent change in global electricity demand, 1991-2025



As in 2023, China and India are on track to post robust increases in electricity demand in 2024, driven by economic growth and rising cooling needs. The United States is also set to see significant demand growth, boosted by stronger economic activity, following a decline in 2023 driven by mild weather. After two consecutive years of decline, the European Union's demand is recovering, albeit at a moderate pace, as various energy-intensive industries ramp-up operations. The sustained increases in electricity consumption in these regions amid rising electrification, combined with robust growth in other emerging economies, is expected to support global electricity demand in 2025 at a similar rate of 4%.

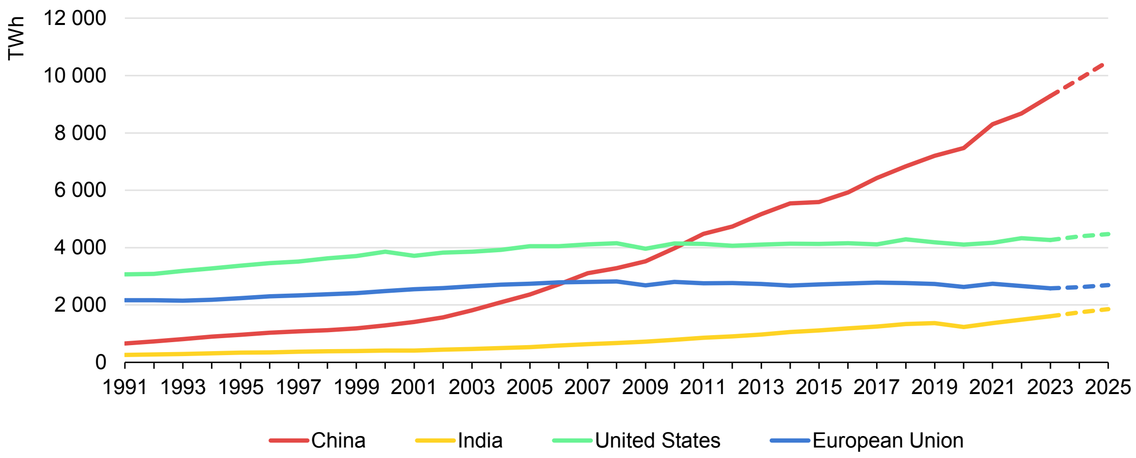
Year-on-year percent change in electricity demand in selected regions, 2019-2025



Electricity demand in China propelled higher by a rapid rise in EV and solar PV production

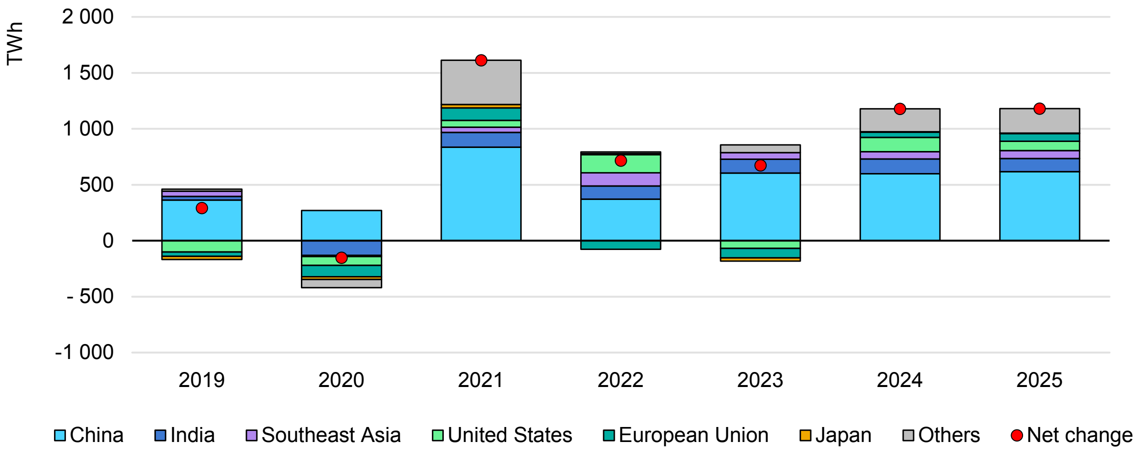
Following a strong 7% y-o-y increase in electricity consumption in 2023, growth in **China** continued at an estimated rate of around 6.5% in H1 2024. For full year, demand growth of 6.5% is forecast, before moderately easing to 6.2% in 2025. Despite the expected slowdown in the Chinese economy and the continuing structural shift to towards becoming less reliant on heavy industries, the rapidly expanding production of solar PV modules, electric vehicles, batteries, and the processing of related materials are all supporting electricity demand growth. Data centres and 5G networks with increasing digitalisation are other important drivers. Over the last three years, China has been adding on average roughly one Germany each year in terms of electricity demand and this trend is expected to continue through 2025.

Electricity demand in selected regions, 1991-2025



In **India**, following robust growth over 8% in 2023, the strong economy, expanding industrial activity and intense heatwaves combined to boost electricity demand growth by 8.5% y-o-y in the first half of 2024. We expect this higher trend to continue for the remainder of the year, with annual growth averaging 8.2% in 2024, before easing moderately to 6.8% in 2025 in line with the GDP projections, and assuming normal weather conditions. The IMF forecast in their April 2024 World Economic Outlook that India's GDP growth will average 6.8% in 2024 and 6.5% in 2025. Indian per capita electricity consumption is currently 20% of that in the European Union. Along with strong economic activity, purchasing of new appliances and air conditioning units will continue to support electricity demand.

Year-on-year change in electricity demand in selected regions, 2019-2025



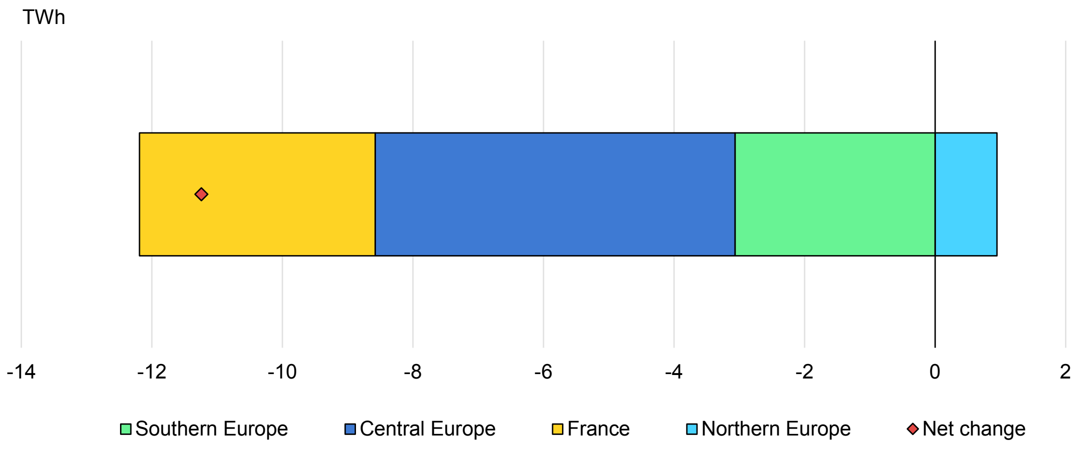
Note: The figures for 2024 and 2025 are forecast values.

After a 1.6% decline in 2023, predominantly due to mild weather, electricity demand in the **United States** rose by 3.8% in the first half of 2024. We expect this robust growth trend to continue for the year, with average annual growth of 3% y-o-y in 2024 and at 1.9% y-o-y in 2025. This is an upwards revision from our previous forecast of 2.5% in 2024 and 0.9% in 2025. One component of these gains is the improved GDP outlook for the United States, which was revised significantly upwards in the IMF's April 2024 outlook (2.7% in 2024 and 1.9% in 2025) compared to the January 2024 report (2.1% in 2024 and 1.7% in 2025). Another driver of growth is the steadily increasing rise in air conditioning consumption generally, but especially due to expected warmer temperatures, as well as the surge in data centre expansions.

European electricity demand recovering but uncertainty over the pace of growth remains

The **European Union**'s electricity consumption decreased by 3.2% in 2023, following a 2.8% decline in 2022. With these two consecutive annual declines, EU electricity consumption fell to levels last seen two decades ago. There has been some demand recovery in the first half of 2024, which posted around a 1% y-o-y increase. Without the influence of weather, the increase would have been an estimated 2%. In most of Europe, the heating season in H1 2024 was warmer compared to the same period in 2023 and resulted in reduced electricity demand. By contrast, Northern Europe (Nordics and Baltics), had a colder heating period during the same time, causing demand for heating in that region to increase.

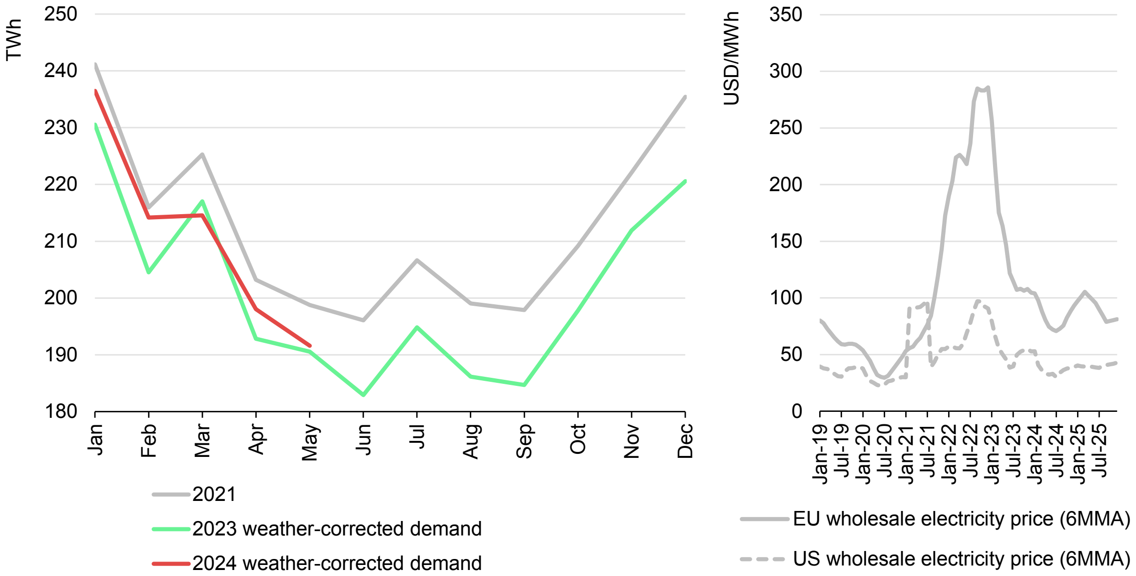
Estimated year-on-year change in electricity consumption for heating in the European Union, January-May 2024



Notes: Southern Europe includes: Bulgaria, Croatia, Cyprus, Greece, Italy, Malta, Portugal, Romania and Spain. Central Europe includes: Austria, Belgium, Czechia, Germany, Hungary, Luxembourg, Netherlands, Poland, Slovak Republic and Slovenia. Northern Europe includes: Denmark, Estonia, Finland, Ireland, Latvia, Lithuania and Sweden. France is shown separately due to the large share of electric heating.

The recovery in electricity demand is expected to gather pace over the remainder of the year and next, with full-year 2024 growth increasing to 1.7% and for 2025 by an even stronger 2.6%. The significant recovery is fuelled by the restart or ramp-up in production at many energy-intensive industries that curtailed operations amid sharply higher energy prices in the 2021-2023 period. Moreover, growth will be supported by continued expansion of electrification in the transport and heating sectors. Nevertheless, uncertainty surrounds the pace of the demand recovery going forward since many energy-intensive industries continue to remain vulnerable to competitive market pressures. Even though energy prices have come down from previous highs, they remain elevated compared to pre-Covid levels.

Monthly EU electricity demand, 2021-2024 (left), and average wholesale electricity prices in the European Union and the United States, 2019-2024 (right)



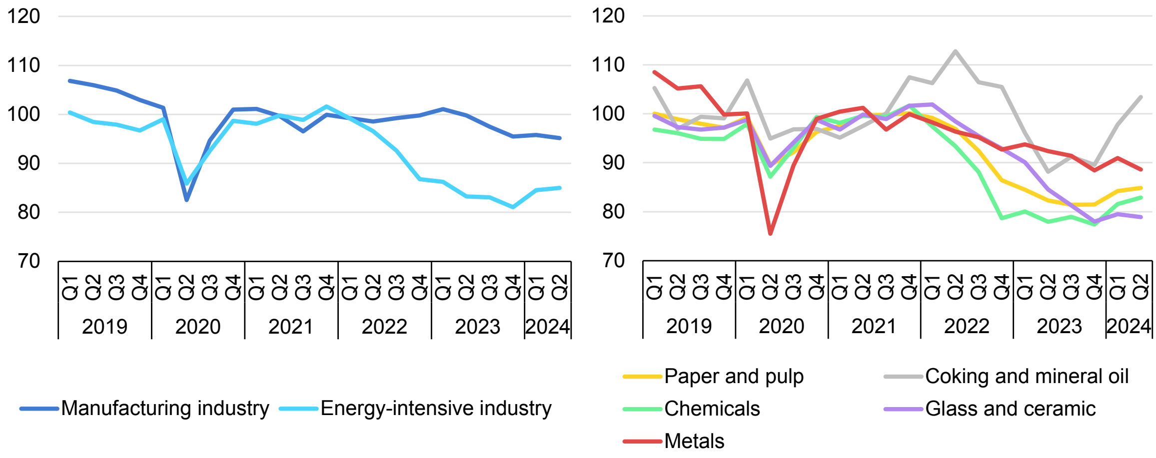
Notes: In the chart on the left, 2023 and 2024 demand is weather-corrected to the base year of 2021 for comparison purposes. The 2021 demand profile corresponds to the realised net demand. In the chart on the right, the plotted average wholesale prices are 6-month moving averages (6MMA).
Source: IEA analysis based on data from Eurostat (2024) and EIA (2024).

Some energy-intensive industries are restarting operations as energy prices stabilise

In our Electricity 2024 report, we tracked the production cutbacks in energy-intensive industries in the European Union amid soaring energy prices, specifically for 2021 and 2022. Some energy-intensive industries were particularly affected by rising energy prices and reduced their output, with production of chemicals and primary metals hit the hardest. After prices eased in late 2023, signs of a recovery in demand started to emerge across regions. Despite this, production curtailments and complete shutdowns continue to persist in various industries.

Overall EU industrial production was 3.3% lower in the first five months of 2024 compared to the same period last year. In May 2024, industrial output was down by 2.5% compared to May 2023. In Germany, for example, the largest economy in Europe, manufacturing during the first five months of 2024 declined on average by 5% compared to the same period in 2023. At the same time, energy-intensive industrial production recovered near 2023 levels in the January-May period, having jumped by 5% from the record lows observed in Q4 2023. However, they were still 14% below 2019 levels. In Germany, while production in the energy-intensive paper (+1%) and chemical (+3%) industries were up y-o-y, the glass (-11%) and metals (-3%) sectors remained weaker. Nevertheless, production in all these energy-intensive industries were higher compared to Q4 2023, showing an overall trend of recovery.

Production indices of selected industries in Germany, 2019-2024



Note: Q2 2024 data is only to May.
Source: IEA analysis based on data from Federal Statistical Office of Germany, DESTATIS.

A number of energy-intensive industries in the European Union announced operational improvements in January 2024, including the primary metals sector. The Liberty Steel plant in Hungary restarted its rolling mills and galvanizing line at the start of the year and began a training programme for employees to operate the planned electric arc furnace (EAF). Tata Steel's Netherlands location restarted in January its 2.5 million tonnes per year (Mt/yr) blast furnace. German steel manufacturer Salzgitter also announced in Janaury the renewal of its steel production after works to reline one of their blast furnaces.

Romania's largest fertilizer and ammonia producer Azomure restarted operations at half of its capacity in early 2024. Glencore's zinc smelter in Nordenham, Germany has been ramping up production since February 2024 after being paused for more than a year. Steelmaker Liberty Częstochowa started technical preparations at its Polish plant in March 2024 to resume crude steel production. In the Netherlands, Nyrstar's Budel zinc plant resumed operations at reduced capacity in May 2024.

High energy prices compared to pre-crisis levels and a sluggish demand outlook weigh on some industries

Elevated energy prices and lethargic demand following the start of the energy crisis in early 2022 combined to force some manufacturers to close plants permanently. Alcoa started the process of selling its aluminium smelting complex at San Ciprian, Spain due to insufficient energy price improvements after having curtailed smelting for two years. In April, Sabic petrochemical company announced the closure of one of their ethylene production plants in the Netherlands to adapt to the market conditions. ExxonMobil announced in April that its 400 000 t/yr steam cracker at the Gravenchon site in France will cease operations over the course of 2024. The unit has reportedly become uncompetitive due to its lower efficiency compared to newer facilities, along with high energy and operational costs. Reno de Medici (RDM) is permanently closing its 110 000 t/yr capacity chipboard plant in Blendecques, France in August, citing high production costs, among other reasons, which make the site uneconomical in the European market.

The steel industry remains particularly under pressure due to a combination of sluggish steel demand and elevated production costs. Flat steel producer US Steel Kosice decided to extend downtime at one of its blast furnaces in Slovakia to Q2 2024, which was previously stopped due to maintenance in March. Italy's steelmaker ADI put one of its blast furnace under temporary shutdown in January 2024, after an increase of its debt to their gas suppliers due to high energy costs. Liberty Steel started decommissioning its last blast furnace in Hungary in August 2023, reporting unsustainable production costs amid low rolled steel prices as the reason, though plans to commission an EAF are being finalised. France's steel pipe producer Vallourec ceased its operations at its Düsseldorf-Rath, Germany plant in Q4 2023.

Heatwaves continued to strain power systems around the world in 2024

In 2024, global temperatures set new records around the globe, with electricity demand for cooling surging and severely impacting power systems. From January to May 2024, the world's surface temperature registered the warmest on record at 1.32°C above the 1901-2000 average, with April 2024 marking a new high.

Many regions grappled with heatwaves that strained power grids and disrupted daily life. In May 2024, the **United States** faced record power demand in Texas due to an intense heatwave, with the Electric Reliability Council of Texas (ERCOT) seeing peak demand of 77 GW, 13% higher than the May 2023 peak.

Across the border, **Mexico** also experienced severe heatwaves in May – one of the two hottest months of the year along with April – causing blackouts where temperatures reached 50°C and with outages lasting for at least four consecutive days. Peak load of around 50 GW was commonly observed. Mexico City, with over 10 million inhabitants, broke heat records three times amid a persistent drought straining water and electrical resources.

Chile's capital of Santiago endured record heatwaves in February. Neighbouring Argentina also suffered extreme heat in the same period, with infrastructure breakdowns amid severely higher energy consumption.

Pakistan's electricity crisis intensified during late May, with a shortfall of 4.5 GW as demand reached 25 GW against a production of 20 GW. This shortage led to prolonged load shedding, especially in rural areas, which experienced 6-8 hours of outages. Meanwhile, at the onset of summer of 2024, **Viet Nam** experienced unprecedented peak load in May due to a severe heatwave, alongside growing industrial activity.

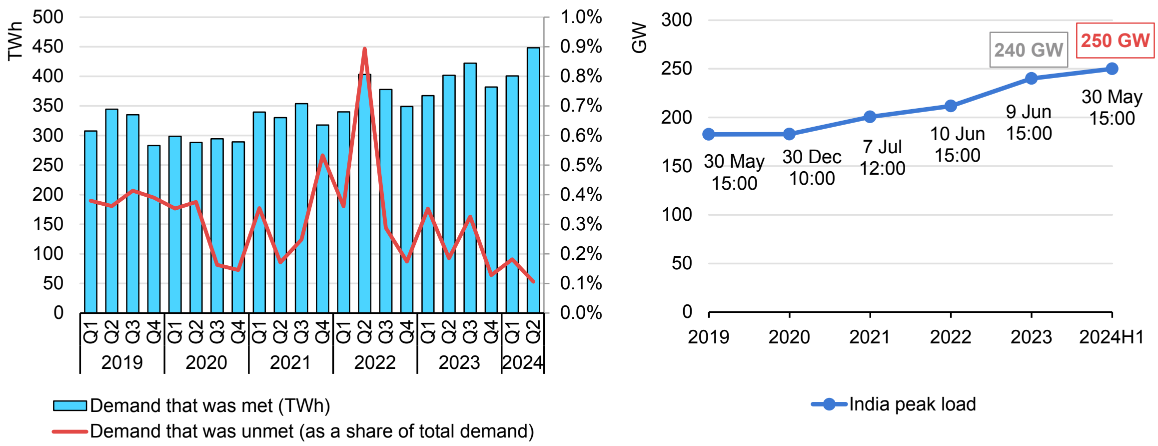
At the tail end of its peak summer heatwave period in early February, **Australia** faced temperatures of over 40°C, sharply raising cooling demand and escalating the use of fossil-fired plants. Additionally, delays in installing transmission lines tied to wind and solar farms are increasing reliability challenges.

In Africa, where meeting electricity demand is already a challenge in many countries, **Chad** and **Mali** experienced severe heatwaves and increased power outages.

India's summer electricity demand surges amidst prolonged heatwaves

In early 2024, India grappled with an unprecedented surge in electricity demand, driven by extreme heatwaves as well as strong growth in industrial and residential power consumption. During this period, the government took emergency measures to manage the situation, including deferring plant maintenance and reopening idled coal units. India also extended the operation of imported coal-based power plants until mid-October from the previous directive through June 2024. Additionally, the government considered similar mandates for gas-based power plants to further enhance capacity.

Met and unmet demand (left), and peak load (right) in India, 2019-2024



Source: IEA analysis based on data from GRID-INDIA (2024).

In late May, India issued a heatwave alert as New Delhi saw temperatures soaring to 49°C. Just a day later, on May 30, 2024, India met an unprecedented maximum power demand of 250 GW driven by intense heat, expanding industrial activities, and heightened residential power consumption. This heatwave has been the longest ever in duration to affect the country, enduring for approximately 24 days in various regions.

Despite this surge in demand, the national electricity transmission network remained stable, with no unscheduled interruptions reported. A peak demand of 258 GW for the rest of 2024 is expected. At the same time, the ability to meet electricity demand has been improving over the last few years. The share of demand that was unmet showed an overall declining trend since the second half of 2022, which continued well into H1 2024.

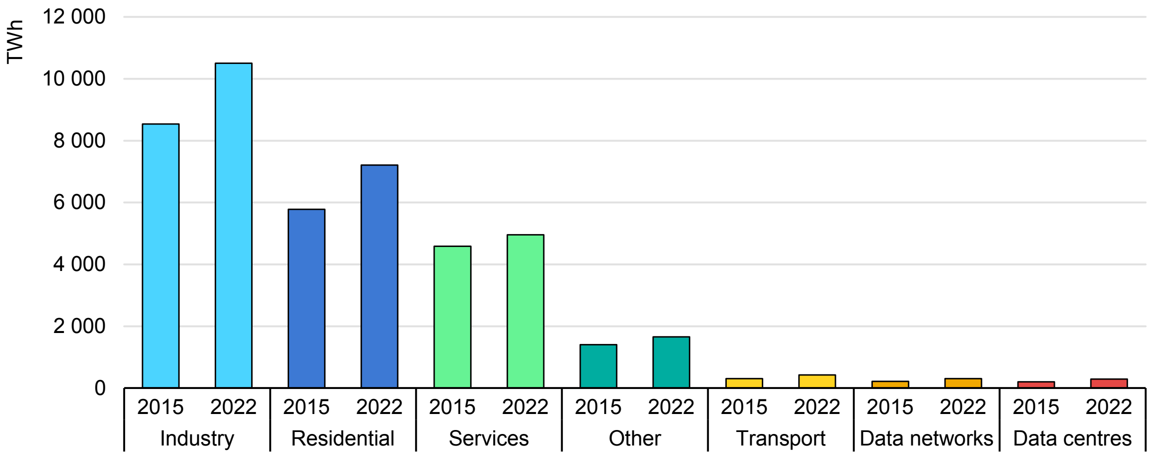
Electricity demand from data centres is in focus with the rise of artificial intelligence

Our Electricity 2024 report provided a comprehensive coverage of the rising power needs of the data centre sector as AI applications become more prevalent and digitalisation gains pace in many regions. Since then, the sector has received considerable attention from regulators and policy makers, as well as in the research and consulting fields, with multiple new studies and projections published. In this section, we provide an overview of the recent developments while also highlighting the need for greater focus on local bottlenecks, improved stocktaking and better understanding of the uncertainty surrounding future projections.

Data centres' global electricity use is currently limited but growing, with local bottlenecks already emerging

Electricity consumption of data centres (excluding cryptocurrencies) is estimated to account for about 1-1.3% of global electricity demand in 2022 and it could see this share rise to a range between 1.5-3% by 2026, according to recent IEA projections. By contrast, electric vehicles, despite their rapid growth, consumed a smaller 0.5% of the world's electricity in 2022, but their consumption is forecast to range from less than 1.5% to around 2% by 2026. By comparison, primary aluminium production, a very electricity-intensive process, currently consumes around 4% of the world's electricity.

Global final electricity demand by sector, 2015-2022



Note: "Services" excludes electricity demand from data networks and data centres.

While data centres' share in global electricity consumption is limited, there are regions where they already make up a sizeable portion of electricity demand. In Ireland, for example, 18% of electricity demand came from the data centre sector in 2022. In Singapore, data centres accounted for around 7% of national electricity use in 2020.

In many regions, power grid connection availability has become a challenge as the data centre sector expands alongside accelerating electrification. In some regions restrictions to commissioning new data centres have been put in place, including Dublin setting grid connection conditions since late 2021. In the Netherlands, from January 2024, new hyperscale data centres are restricted in most locations due to grid constraints, among other reasons. Singapore had a temporary moratorium put in place in 2019, which has been relaxed in 2022. The pressing need to invest in new infrastructure to meet the growing electricity demand, including data centre power load, is a key focus in various parts of the United States, including Virginia, according to Dominion Energy, and ERCOT in Texas. The US government launched the Federal-State Modern Grid Deployment Initiative in May 2024, recognising the need to upgrade the grids in the face of growth from large data centres, among other demand sources.

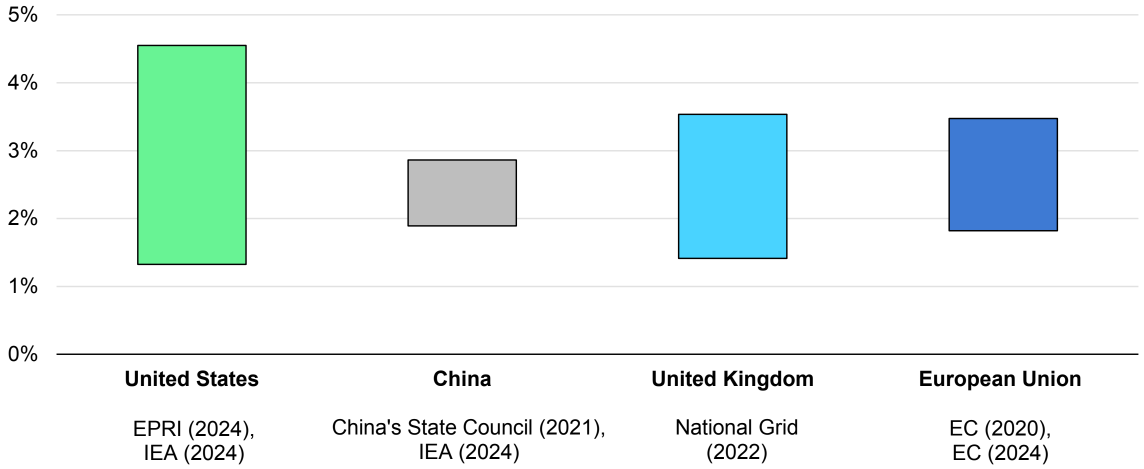
To circumvent grid connection challenges or to reduce dependency on the grid, some data centre providers are increasingly looking into on-site generation. For example in China, where data centres and 5G networks are growing sources of electricity demand, technology company Tencent installed around 10 MW of rooftop solar with battery storage at its Tianjin cloud data centre. In the United States, Amazon Web Services (AWS) has acquired Talen Energy's data centre connected to the Susquehanna nuclear power plant, with plans to expand the data centre's capacity. Fossil-fuel based (sometimes ad-hoc) on-site solutions are also being considered by others. Gas Networks Ireland reportedly has received 20 formal connection enquiries from data centres. A current proposal in Ireland explores the possibility to allow private businesses to build and operate their own power lines, and a policy towards advancing this matter is expected by late 2024.

Stocktaking needs to be improved, but initiatives and regulations in different regions are gaining pace

Electricity consumption of data centres has historically shown a wide range of estimates across sources. A lack of reliable data in many countries contributes to the substantial uncertainty in consumption levels. For example, studies for the European Union show that the share of data centres' consumption in total electricity demand in 2022 could range between 1.8% to 3.5%. In the United States, estimates range between 1.3% to 4.5% in 2022, and in China it can range from 1.9% to 2.9% according to our estimates based on the projections from China's State Council. In some individual countries, the range of uncertainty is even greater.

Global data centre deployment trends, evolution of technology towards higher power-demanding servers and recent announcements of construction plans underline the importance of better stocktaking of data centres. Improving the collection of energy consumption data of the sector is important to correctly identify past developments. This in turn helps to better understand future trends in order to inform the public debate more accurately.

Range of data centre electricity consumption estimates as a share of total electricity demand in the United States, China and Europe for the year 2022



Note: China's State Council (2021) provides historical data for 2020 and a forecast value for 2030; 2022 values are interpolated. The range of the values results from the uncertainty in the source, whether it includes data transmission networks or not. The European Commission (2020) provides historical data up to 2018. The values for 2022 are based on scenarios presented in the study.

Sources: IEA analysis based on European Commission (2020), Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market; China's State Council (2021), Green data centers in focus; National Grid ESO (2022), Data Centres; IEA (2024), Electricity 2024; data from European Commission JRC (2024), Energy consumption in data centres and broadband communication networks in the EU; EPRI (2024), Powering Intelligence: Analyzing Artificial Intelligence and Data Centre Energy Consumption.

There is increased momentum in regulation and initiatives for improved data collection of the sector in various regions. In the **European Union**, Energy Efficiency Directive 2023/1791 requires such obligations. It calls for data centres that have a minimum 500 kW of power demand of IT-installed capacity to report to the Commission various indicators on a yearly basis. Building on this directive, the Commission established through the Delegated Regulation 2024/1364 the first phase of a common scheme for rating the sustainability of data centres, by way of introducing the key performance indicators that data centre owners and operators are required to report on. The reporting is required to be done by 15 September 2024, then by 15 May 2025, and every year thereafter. Selected indicators will be made publicly available at an aggregated level through the EU's dedicated database. Reporting includes electricity consumption and its share from renewable sources, and energy efficiency ratings reported as Power Usage Effectiveness (PUE), which compares the total power used in the facility with the power consumed by the IT equipment. Furthermore, the directive requests reporting use of waste heat, incoming and outgoing data traffic, among other data points. By May 2025 the Commission will make an assessment of the sector's energy efficiency to establish the next phase of the rating scheme and/or minimum performance standards to achieve net zero emissions.

Germany's new Energy Efficiency Act adopted and expands on the EU's Energy Efficiency Directive. In addition to incorporating the EU's scheme, it extends the list of reporting metrics that data centres are required to report on by 15 August 2024. It also includes operational mandates such as PUE targets for new and existing data centres. Facilities coming online on or after 1 July 2026 are required to meet a PUE of 1.2. Already existing data centres must ensure a max PUE of 1.5 by 2027 and downwards to 1.3 by 2030. Beyond energy efficiency, data centres are required to procure 50% of their electricity from renewable sources by 1 January 2024, increasing to 100% by 1 January 2027. Note that while the industry global average PUE is estimated to be around 1.5-1.6 in 2023, average values of some industry players are lower. Google, for example, stated an average of 1.1 for its fleet in its latest environmental report.

In the **Netherlands,** Statistics Netherlands (CBS), the national statistics institute, published estimates in 2022 on data centre electricity consumption based on data collected from grid operators. The Netherland's Environmental Act, which consolidates the environmental regulations, came into effect in January 2024 and will also apply to data centres. This is in addition to the list of recognised measures (i.e. energy saving guidelines) that data centres must follow with regard to their cooling and power supply systems.

In the **United States**, although not targeted at the data centre sector but rather at the crypto mining sector, the Energy Information Administration launched a 6-month reporting period, which was however discontinued following a court case. As part of the mandatory survey, data such as monthly electricity consumption as well as average and maximum power demand from more than 80 cryptocurrency mining facilities in the country were to be reported. In February 2024, a bill to study the environmental impacts of AI was introduced, and the House Committee on Energy and Commerce held a hearing in June about the energy consumption of AI. The Commercial Buildings Energy Consumption Survey (CBECS), a national survey that collects information on the stock of US commercial buildings since 1979, also includes data centres. However, data collection on data centres has reportedly not been comprehensive, in part due to the voluntary nature of the survey. At the state level in Virginia, a local regulation on data centres was proposed in January 2024, requiring a quarterly electricity consumption report, however its approval process is not scheduled to take place until 2025.

Singapore is considering introducing a Digital Infrastructure Act and creating an inter-agency taskforce to provide further support to digital infrastructure service companies. Both actions intend to mitigate IT systems failures and create reporting requirements for regulated entities to avoid crisis events like that in October 2023 when banking services were disrupted for several hours.

In **Australia**, data centres that provide services to the local government will have to comply with environmental performance regulations by July 2025 under the National Australian Built Environment Rating System (NABERS). This system mandates data centres to meet building requirements such as energy efficiency, water usage, waste management and indoor environment quality.

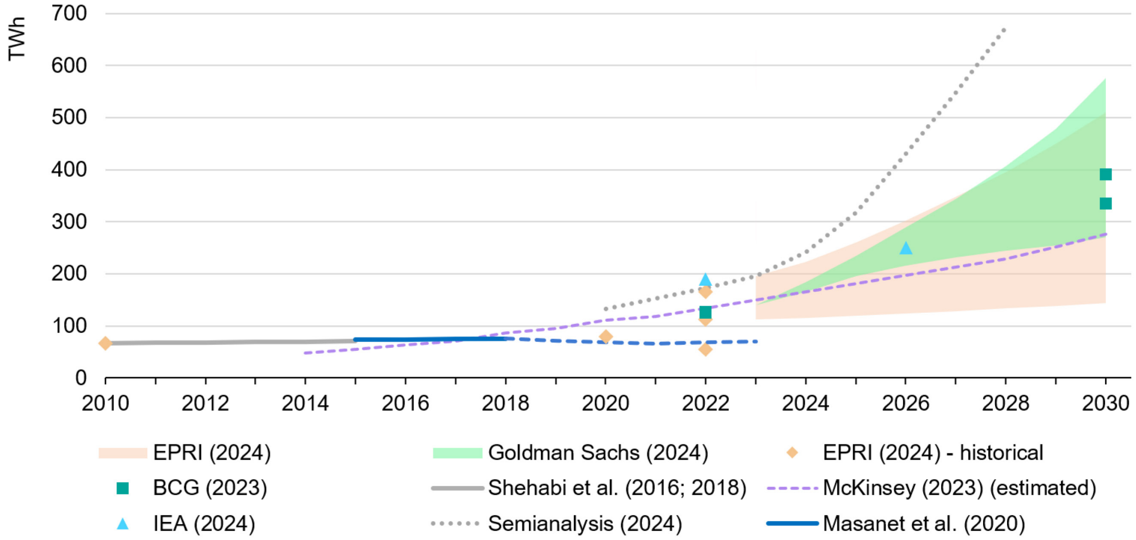
Electricity demand projections of data centres exhibit a wide range of uncertainty

Estimates for future data centre and AI energy consumption are highly uncertain. The uncertainty in projections is most notable in the case of the United States, where consulting firms, investment banks, industry analysts and industry organisations have projected data centre and AI energy use to 2030. They forecast data centres could account for anywhere between 4% to 10% of national electricity use in 2030.

Regional market trends in the United States and the assumptions regarding the deployment pace of new facilities are important factors driving this uncertainty. It should also be noted that some of the analyses follow rather simplistic extrapolations, assuming certain compound annual growth rates (CAGR) depending on the scenario. Some other studies that follow a more bottom-up approach assume that data centre operators build all the data centres for which they apply to utilities, which can lead to double counting as requests can be made to multiple network operators.

Uncertainties related to demand, technological advancements, and efficiency improvements make it difficult to project future energy consumption from data centres. In particular, the energy requirements for AI are very uncertain given the increasing adoption of AI applications, particularly generative AI. At the same time, AI accelerators such as graphics processing units (GPUs) are also becoming increasingly energy efficient even as they are also more powerful. US-based NVIDIA, which accounted for around 95% of global market share for AI accelerators (as of February 2024), reported that its new generation of chips over the older generation is 25 times more energy efficient. Despite this, as computation power and efficiency increases, some degree of rebound effects cannot be ruled out, since the corresponding decrease in the cost for computation can drive additional demand.

US data centre electricity demand projections from different sources, 2010-2030



Notes: The ranges in the figure correspond to the minimum and maximum projections provided in the selected sources. From Shehabi (2018), "Best practices" and "Frozen Efficiency"; from BCG (2022), "GenAI min" and "GenAI max"; from Goldman Sachs (2024), "Bear case with AI" and "Bull case with AI"; from EPRI (2024), the lower bound of "Low growth" and the upper bound of "Higher growth" scenarios are shown. Demand figures for McKinsey (2023) are IEA estimates based on reported data centre power consumption, assuming a utilisation rate of 60% and PUE of 1.5. Masanet et al. (2020) provides estimates for North America. These have been adjusted with a factor of 0.9 to correspond to the US values.

Source: Shehabi et al. (2016), United States Data Center Energy Usage Report; Shehabi et al. (2018), Data center growth in the United States: decoupling the demand for services from electricity use; Masanet et al. (2020), Recalibrating global data center energy-use estimates; BCG (2023), The impact of GenAI on Electricity: How GenAI is Fueling the Data Center Boom in the U.S.; McKinsey (2023), Investing in the rising data center economy; IEA (2024), Electricity 2024; Goldman Sachs (2024), AI, data centers and the coming US power demand surge; Semianalysis (2024), AI Datacenter Energy Dilemma - Race for AI Datacenter Space; EPRI (2024), Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption.

Next to renewables, nuclear and geothermal power are becoming attractive for data centres

Some data centre providers are working to meet their power needs with carbon-free electricity, based on a portfolio of different technologies including wind, solar, storage and firm clean energy. In this context, the data centre sector has traditionally been a driver of clean energy deployment via power purchase agreements (PPA). In May 2024, in a record-breaking PPA, Microsoft signed a USD 10 billion 5-year agreement to build 10.5 GW of solar and wind power capacity in the United States and Europe. In New Zealand, telecommunications company Spark signed a 10-year PPA for 63 MW of new solar power that will start supplying electricity by January 2025. AWS signed in April 2024 a 105 MW PPA to procure electricity from a wind farm west of Dublin, Ireland and committed further investment towards 800 MW of new renewable energy projects across the country. Similarly in Ireland, Google has signed a PPA with Power Capital Renewable Energy for 58 MW of new-to-the grid capacity from the Tullabeg Solar Farm.

The need for firm low-emission power generation with a stable profile is prompting many players in this sector to look into nuclear and geothermal energy. AWS is expanding a data centre next to the Talen Energy's Susquehanna nuclear power station in Pennsylvania with a potential 960 MW power load met by a 10-year PPA. In particular, small modular reactors (SMR) are being considered by various companies. Virginia-based GEP announced plans to build a data centre campus that would be eventually powered by SMRs on-site, complemented by natural gas and hydrogen-blend generators, to be converted to fully hydrogen later on. Norsk Kjernekraft, a Norwegian power company, announced intentions to provide off-grid power for data centres with SMRs. The data centre developer Equinix signed an agreement with a pre-payment to enter a PPA with Oklo, a company that designs SMRs, to be supplied up to 500 MW of nuclear power.

In May 2023, Microsoft signed world's first PPA on fusion power with the fusion energy company Helion. Planned to come online by 2028, Helion's plant is to provide Microsoft with 50 MW of power following an initial one-year ramp-up period. While the agreement reportedly includes significant penalties to Helion if it is unable to deliver, the details of the agreement were not publicly disclosed at the time of the publication of this report.

Microsoft, alongside AI company G42, are investing USD 1 billion in a data centre powered completely by geothermal energy in Kenya. Microsoft also secured a 51 MW geothermal 10-year PPA in New Zealand that is expected to start supplying electricity by late 2024. A pilot 3.5 MW enhanced geothermal system has been providing power to Google's data centres in Nevada since November 2023. Google and NV Energy signed an agreement that includes 115 MW of enhanced geothermal power capacity in the United States. The partnership includes a novel market rate structure called Clean Transition Tariff aimed at supporting the investment of geothermal, nuclear and long-duration storage technologies. Google, Microsoft and the North American steelmaker Nucor announced in March 2024 that they are working on a new demand aggregation model to facilitate first-of-a-kind projects for advanced clean electricity technologies, including advanced nuclear, geothermal, clean hydrogen and long-duration energy storage, among others.

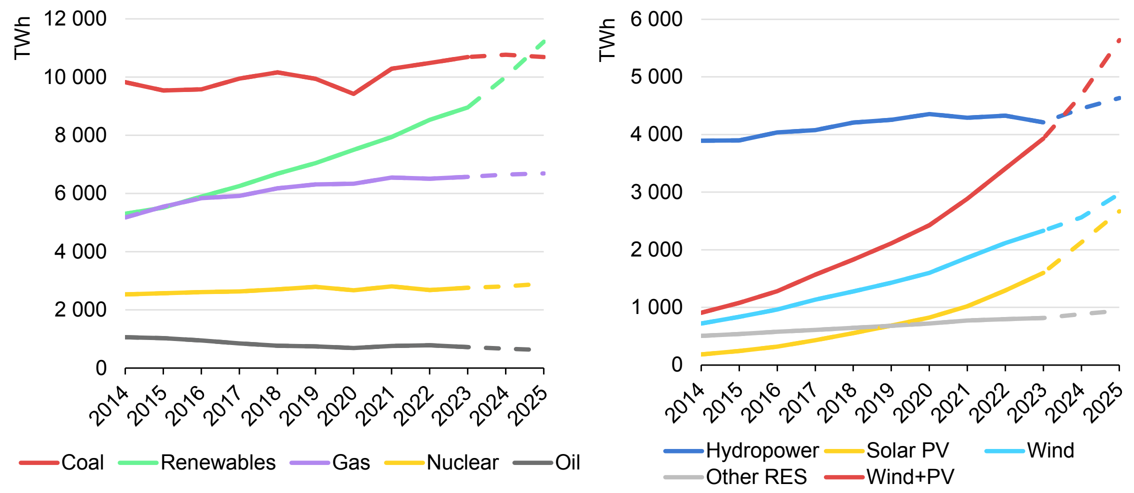
While the concluded PPAs and other announced plans for powering the data centre sector from novel clean energy sources (e.g. SMR and fusion) can provide these technologies with increased momentum, it should be noted that these are at early stages of technological maturity and significant uncertainties regarding delivery timelines cannot be ruled out.

Supply: Renewable generation will overtake coal-fired power in 2025

Global coal-fired generation is anticipated to increase slightly in 2024, growing by less than 1%, following a 1.9% increase in 2023. In our previous Electricity 2024 report, we had estimated global coal-fired generation to contract in 2024 under normal weather and economic conditions. Nevertheless, declines in Europe this year will be offset by substantial increases in Asia, driven by strong electricity demand growth in China and India. In contrast to the previous year, US coal-fired generation is also expected to remain robust in 2024 amid rising electricity demand and reduced coal-to-gas switching. In addition, lower hydropower output due to droughts in many regions such as in India, Viet Nam and Mexico are boosting fossil-fired generation this year despite strong growth in wind and solar PV. However, assuming a return to more normal weather conditions, we expect coal-fired generation to slightly decline by less than 1% in 2025 and enter a plateau, as it is increasingly displaced by rapidly growing wind and solar PV generation.

The transition towards renewable energy sources is set to achieve a significant milestone by 2025, with total renewable generation poised to overtake coal-fired output. The share of renewables in global electricity supply climbed to 30% in 2023 and is projected to reach 35% by 2025. Concurrently, the reliance on coal is expected to lessen, with its share falling from 36% to 33% over the same period.

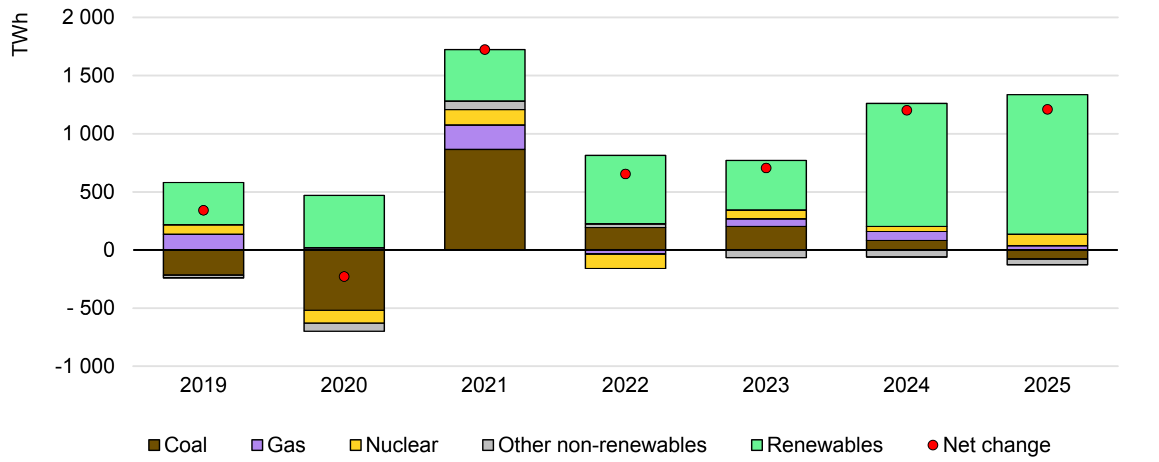
Global electricity generation by source, 2014-2025



Solar PV and wind energy are at the forefront of this transformation, with their combined share anticipated to rise from 13% in 2023 to 15% in 2024 and to 18% in 2025 – up from a mere 4% a decade earlier. Wind and solar PV generation together are expected to provide an additional 750 TWh in 2024 and more than 900 TWh in 2025. The year-on-year increase in 2025 is more than double the average annual growth in output over 2019-2023 and is equivalent to the total electricity demand of France and Italy combined. Electricity generation from solar PV and wind generation is set to surpass that from hydropower in 2024, marking a pivotal moment for the sector.

Global gas-fired generation growth is forecast at an average 1% in both 2024 and 2025, as strong declines in Europe are offset by increases in Middle East due to continued switching from oil- to gas-fired generation, and in Asia amid rising LNG imports. Nuclear generation is expected to continue growing by 1.6% in 2024 and 3.5% in 2025, as the maintenance of the French nuclear fleet progresses and new reactors in China, Korea, and Europe as well as restarted ones in Japan become operational. As we stated in our previous report, global nuclear generation is on track to reach a new record high in 2025, surpassing the previous one in 2021.

Year-on-year global change in electricity generation by source, 2019-2025



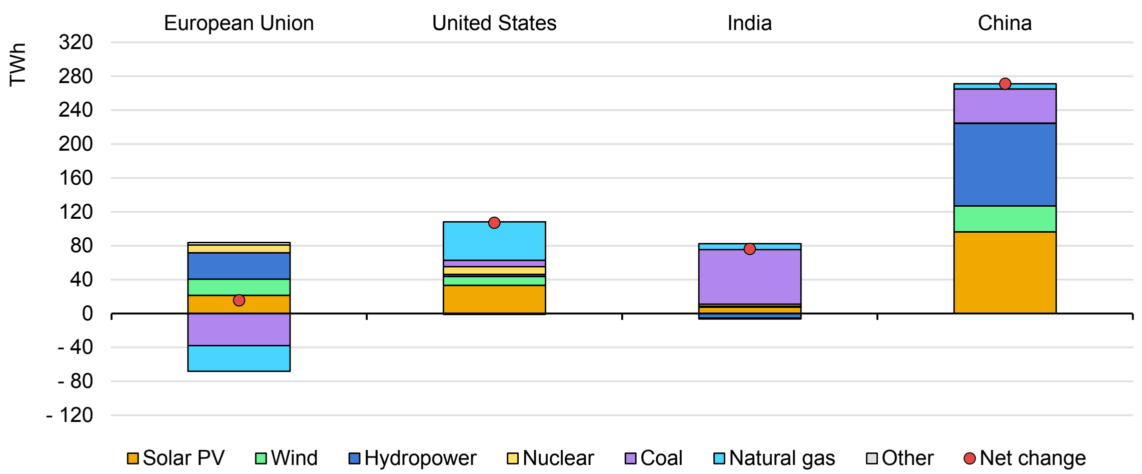
IEA. CC BY 4.0.

Notes: *Other non-renewables* includes oil, waste and other non-renewable energy sources. The figures for 2024 and 2025 are forecast values.

Fossil-fired generation fell in the EU but rose in India, China and the US in H1 2024

After having been affected by droughts three years in a row, hydropower output in **China** started to rebound in H1 2024, with an increase of 21% y-o-y. Solar PV generation is estimated to have increased by over 35% during the same period. Wind generation was up by 7%. Despite this, coal-fired power remained resilient and grew by an estimated 1.5% in H1 2024, driven by robust electricity demand in China. Whether the higher coal-fired growth trend continues through the remainder of the year will depend on the pace of rising demand, and especially on the extent of the hydropower recovery. Assuming average annual electricity demand growth of 6.5% in 2024 and an increase of 11% in hydropower output, we estimate coal-fired generation in China will rise by a much more moderate 0.8% on average for the full year. Coal-fired power will also be kept in check in 2024 by the significant year-on-year growth forecast for solar PV (+45%) and wind (+9.5%) generation.

Year-on-year change in electricity generation by source in selected regions in H1 2024

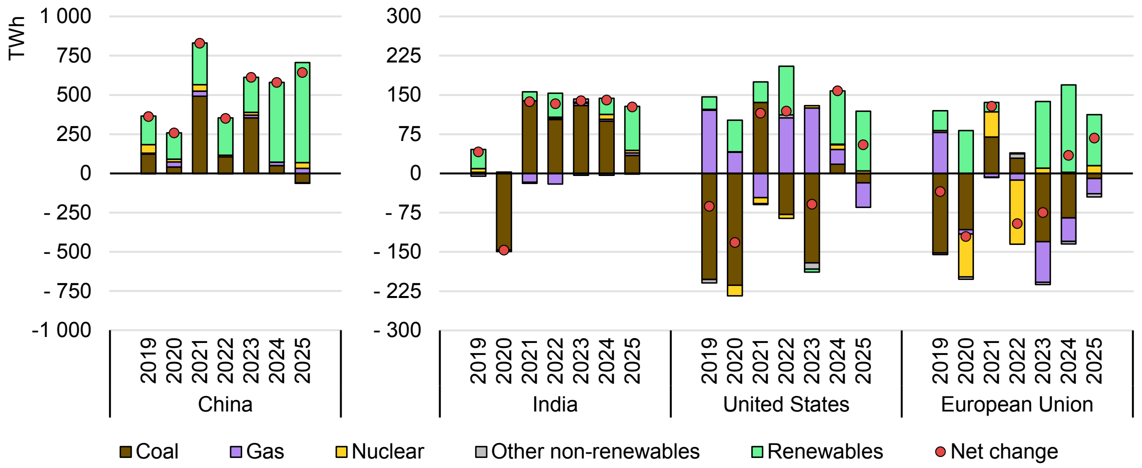


Notes: Net electricity generation is shown.

Indeed, given a higher rebound in hydropower, 2024 could see coal-fired generation in China remaining flat or even record a decline. Assuming significant demand growth of 6.2% and average hydro conditions for 2025, Chinese coal-fired output would decline by 1% next year. This will also be supported by the continued growth in solar (+36%) and wind (+29%) output as well as increased nuclear generation (+9%) due to new reactors becoming operational. While the downward pressure on Chinese coal-fired output is largely structural, weather impacts and economic shocks can cause upticks in individual years. By contrast, gas-fired generation in China will remain robust and is forecast to rise by above 7% on an annual basis in 2024 and by a further 10% in 2025.

In **India**, the drought conditions that emerged in 2023 following the onset of El Niño continued to have an impact in 2024, resulting in an 8% y-o-y decline in electricity generation from hydropower in the first half of 2024. As a result, amid strong electricity demand growth coal-fired generation was up by 10% in H1 2024. Gas-fired output rose by 50% during the same period. This increase follows an emergency clause invoked by the government mandating companies to operate underutilised gas-fired power plants by importing fuel. At the same time, the mandate for imported coal-based power plants to operate at full capacity was extended until 15 October 2024 due to expected high demand during the peak summer period. As a result, we expect coal-fired generation in India to remain robust, growing by 7% on average for the full year. Over the same period, we expect solar PV generation to increase by 32% and wind by 4%, followed in 2025 by over 20% growth in solar PV generation and 3% in wind. As renewable output grows, we expect coal-fired generation to record a limited increase of around 2% in 2025, assuming normal weather conditions.

Year-on-year change in electricity generation by source in selected regions, 2019-2025

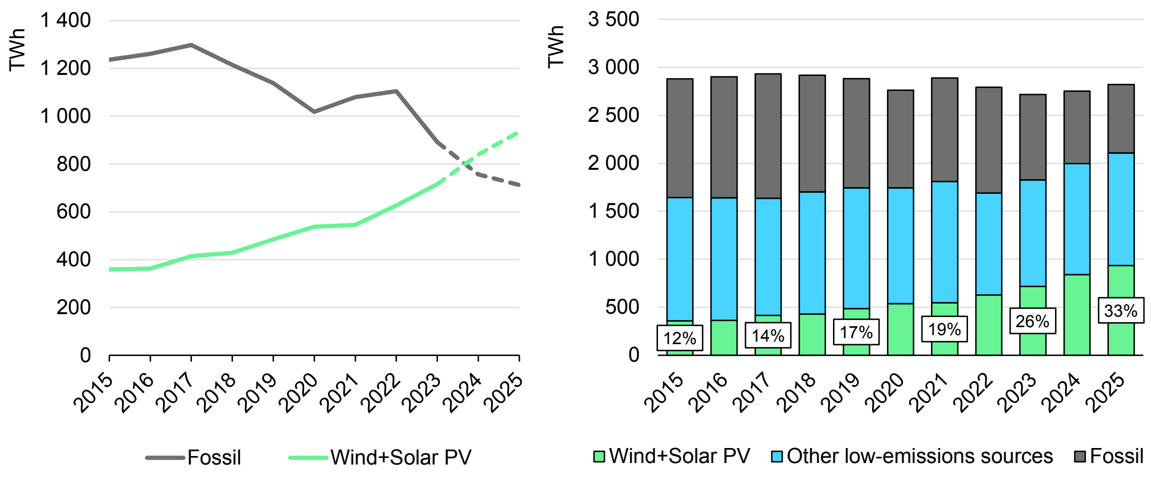


Notes: *Other non-renewables* includes oil, waste and other non-renewable energy sources. The figures for 2024 and 2025 are forecast values.

In the first half of 2024 the **United States** posted a 6% rise in gas-fired generation and coal-fired increased by 2.5%. Nuclear generation rose by 2.5% after the Vogtle Unit 4 entered commercial operation in April 2024. Solar PV generation saw strong growth of 34% whereas wind grew by 4.5% over the same period. Hydropower generation recovered slightly from the low levels observed in 2023 due to early snowmelt, up by 2% y-o-y in H1 2024. For full year 2024, renewables are forecast to increase by 11% and in 2025 by another 11%. Following a sharp y-o-y decline in 2023 of almost 20%, coal-fired generation is anticipated to increase by around 2% in 2024 amid rebounding electricity demand and limited availability of further coal-to-gas switching. Despite this, coal-fired output will be less than half what it was a decade ago. The 2024 uptick in coal-fired generation is expected to be followed by a 2% decline in 2025, with various coal-fired power plants planned to be retired through the end of the year. Gas-fired generation is forecast to grow by 1.5% in 2024 and then decline by more than 2% in 2025 as renewables use continues to expand.

In the first half of 2024 the **European Union** saw generation from hydropower increase by 20%, solar PV by 18%, and wind by 9%. At the same time, coal-fired generation declined by 22% and natural gas fell by 17%. The strong growth in renewables amid a slow recovery in electricity demand is expected to continue to reduce fossil-fired generation in the European Union in 2024 and in 2025. Marking a major milestone, wind and solar PV generation is set to surpass fossil-fired output in the European Union in 2024, with their combined share in total supply rising from 26% in 2023 to 30% in 2024 and to 33% in 2025. In line with these gains, the share of all renewable energies in total generation is expected to reach 50% in 2024 and 52% in 2025, compared to 44% in 2023. Assuming normal weather conditions in H2 2024 and demand growth of 1.7% for the full year, we forecast a decline in coal-fired generation of 24% and gas of 10% in 2024. With the ongoing recovery in the French nuclear fleet and the increase in renewables, further contractions in coal (-4%) and gas (-7%) are expected in 2025.

Electricity generation by source in the European Union, 2015-2025

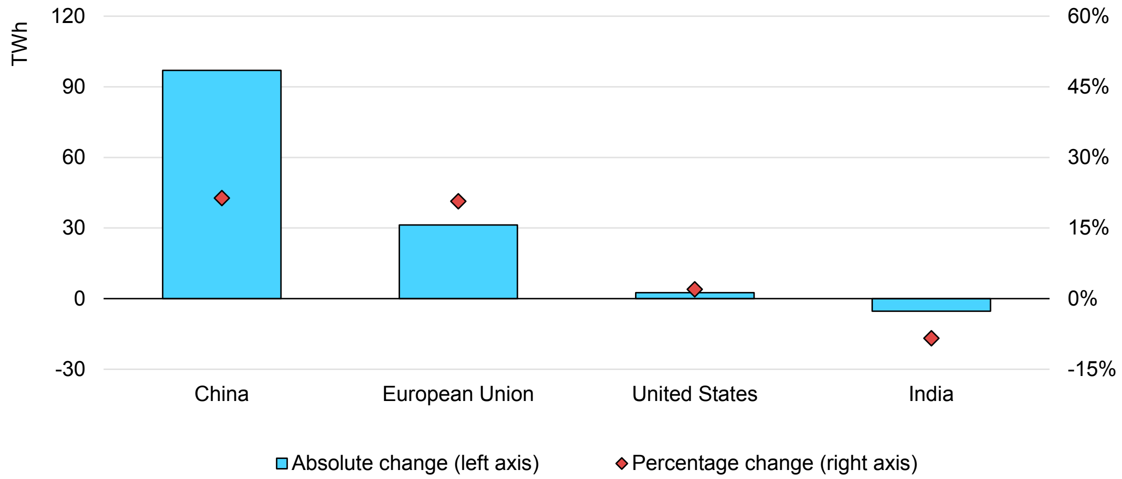


Note: The figures for 2024 and 2025 are forecast values.

Hydropower output was reduced in various regions in H1 2024 due to weather impact

While hydropower generation increased strongly year-on-year in China (+21%) and the European Union (+20%) in H1 2024, numerous other regions were affected by drought conditions. Lower hydropower output in these areas resulted in rising fossil-fired generation to meet demand. In some cases, the lack of adequate capacity resulted in load shedding and outages.

Change in hydropower output in selected regions, H1 2024 versus H1 2023



2023 was the warmest year on record, and the 2023/24 El Niño period has so far been one of the strongest ever recorded. El Niño usually has a stronger influence on the global climate in its second year of development – in this case 2024. El Niño typically brings decreased monsoon rainfall in Southeast Asia. By March, **Indian** reservoirs had fallen to their lowest level in 5 years. During the first half of 2024, hydropower electricity generation was down 8% when compared to the same prior year period.

In the first five months of 2024, hydropower generation in **Viet Nam** was more than 20% lower year-on-year. During the same period, electricity demand grew by around 11% compared to the same period in 2023. This was attributed to increased use of air conditioners in the wake of an intense heat wave, driven in part by El Niño. This heat wave coincided with reduced rainfall. Viet Nam's state-owned utility started conserving water at hydropower dams in early 2024 in anticipation of a prolonged dry season.

Reservoirs in **Colombia** hit record lows of 30% in April in the wake of El Niño-induced droughts. At the same time, electricity demand in Colombia grew more than 8% in March 2024, compared to the previous year. To mitigate this, Colombia issued a resolution requiring maximum utilisation of variable renewable energy (VRE) and removing penalties for deviations from power targets for such generators. Colombia also stopped electricity exports to Ecuador. In response, the government of **Ecuador** began electricity rationing. Relief came for Ecuador in late April, as extreme rains fell late in the month, leading to the end of rationing from May.

In **Mexico,** the first half of 2024 was characterised by heatwaves and droughts, which have been particularly intense in the northwestern states of the country. For example, the 135 MW hydropower plant El Novillo ceased electricity generation since April due to low water levels (around 11%) and water pumping for the 422 MW hydropower plant Huites has been halted since May to prevent equipment damage while water levels during that period have been preserved close to 20%. The 1 120 MW Infiernillo plant in the southeast of the country has seen a constant reduction of its storage levels, from approximately 70% in April to 46% in July.

The 2023/24 winter in **Canada** was the warmest on record, with the country receiving well below average amounts of precipitation. In January 2024, hydropower electricity generation reached the lowest level for the month since 2009. In British Columbia, snowpack started melting earlier than in past years, with snowpack in May reaching 66% of the usual levels.

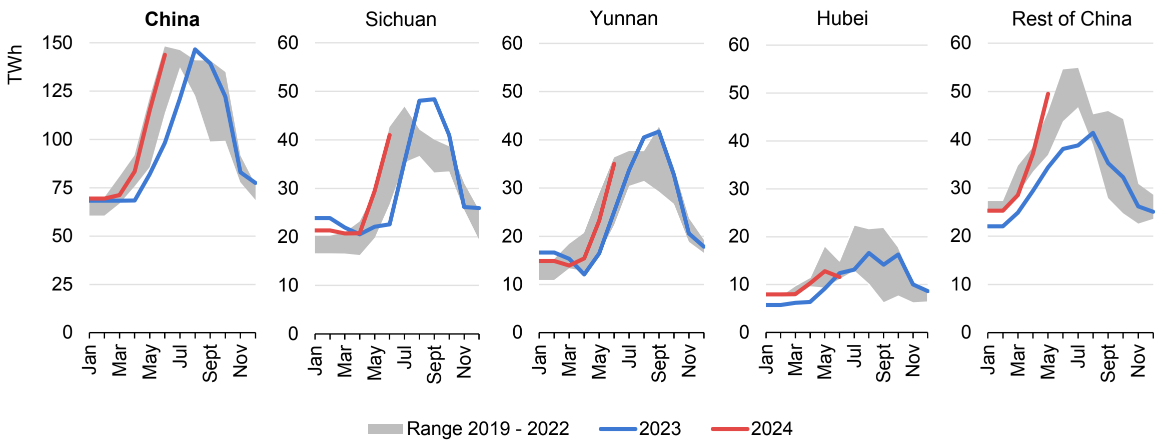
El Niño is known to bring below-average rainfall and high temperatures to **Southern Africa**. In 2024, the region recorded the lowest rainfall levels in January and February in at least 40 years. At the start of June 2024, Zimbabwe's Lake Kariba, which provides the bulk of hydropower electricity consumed in both Zimbabwe and Zambia, was at around 12% fullness, compared to 30% the prior year. In December 2023, the Zambezi River authority, which manages the dam, had to reduce water allocation for power generation due to drought conditions.

The hydropower recovery in China in H1 2024 was strong, although with differences between provinces

After suffering a series of droughts since the middle of 2022, hydropower generation saw a significant recovery in the first half of 2024, up 21% y-o-y. Spring rains in China arrived earlier than usual and were heavy, reaching record levels in some areas. Forecasts suggest hydropower generation in **China** could rebound by around 10-12% for the complete year of 2024.

Four drainage basins in the south of China are responsible for most of the country's hydropower generation – the Yangtze River, Pearl River, Southeast Rivers and Southwest Rivers. Most of the annual precipitation in China's southwest usually occurs between June and August during the East Asian Monsoon season. Rainfall levels during this period will subsequently play an important role in determining the extent of the hydropower recovery in 2024.

Hydropower generation in China and in the largest hydropower provinces, 2019-2024



Source: IEA analysis based on data from National Bureau of Statistics of China.

June and early July brought droughts to northern regions such as Gansu and Shaanxi, whereas provinces in the south like Fujian and Yunnan saw floods. China's National Bureau of Statistics (NBS) reported an almost 40% y-o-y increase in hydropower electricity output for May, displacing coal-fired generation. The Yangtze River reportedly experienced flooding in the same period, driving water levels of the Three Gorges Dam to 161 metres, close to its 175 m reservoir height. The state-owned China Three Gorges Corporation (CTG), which also manages several large hydro plants in the province of Hubei, reported heavy rains during June. In the southern province Guangxi, 30 hydrologic stations reported water levels above the warning levels.

Emissions: Power generation CO_2 emissions plateau in 2024-2025

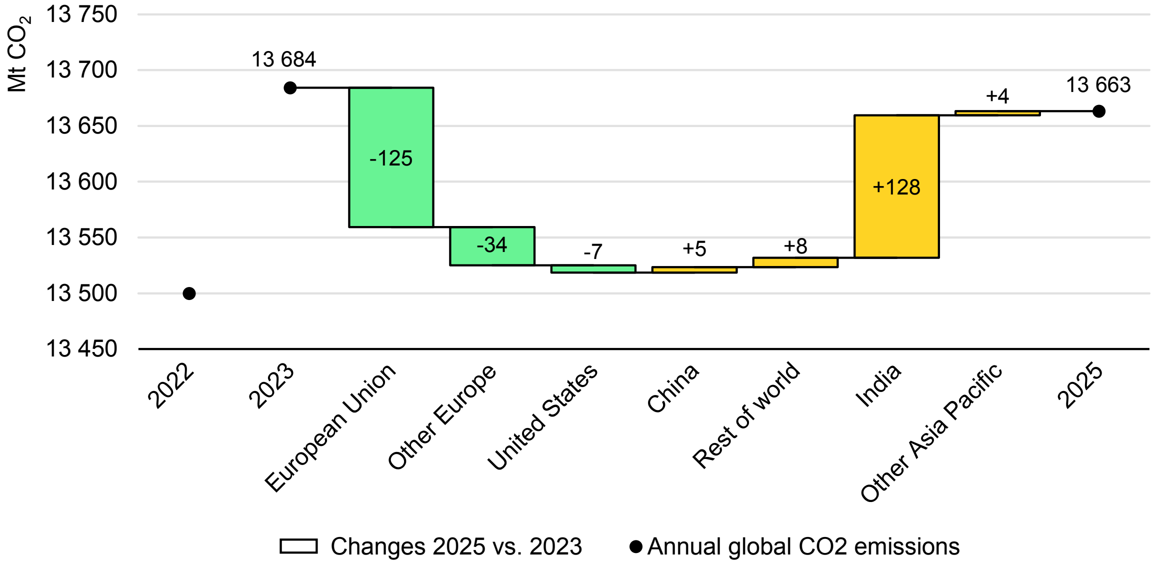
Global emissions from electricity generation rose by 1.4% in 2023, after rising by 1.6% in 2022. This was despite hydropower in 2023 falling more than 2%, which boosted fossil-fired generation in many parts of the world to meet electricity demand. In 2024, the massive gains in wind and solar generation globally, combined with the recovery in hydropower in China, constrained the increases in electricity output from fossil fuels. As a result, we expect CO_2 emissions to remain relatively flat, up about 0.5%. For 2025, we anticipate emissions to decline at a similar rate as renewables continue to grow and displace fossil-fired supply. However, deviations from the normal weather conditions, such as intense heatwaves, cold spells or below-average hydropower trends, can cause an uptick in emissions in individual years. Nevertheless, the structural shift from fossil fuels to renewables in electricity generation is set to remain robust.

Increased emissions in India are more than offset by declines in Europe and the United States

Multiple regions in the world are expected to start seeing falling emissions from electricity generation out to 2025. The largest decline is expected from the European Union, which makes up most of the total contraction, followed by Other Europe. US power sector emissions are expected to record a slight decline, whereas in China they are expected to increase slightly. India and Southeast Asia will continue to post higher emissions from the power sector due to rising coal-fired generation.

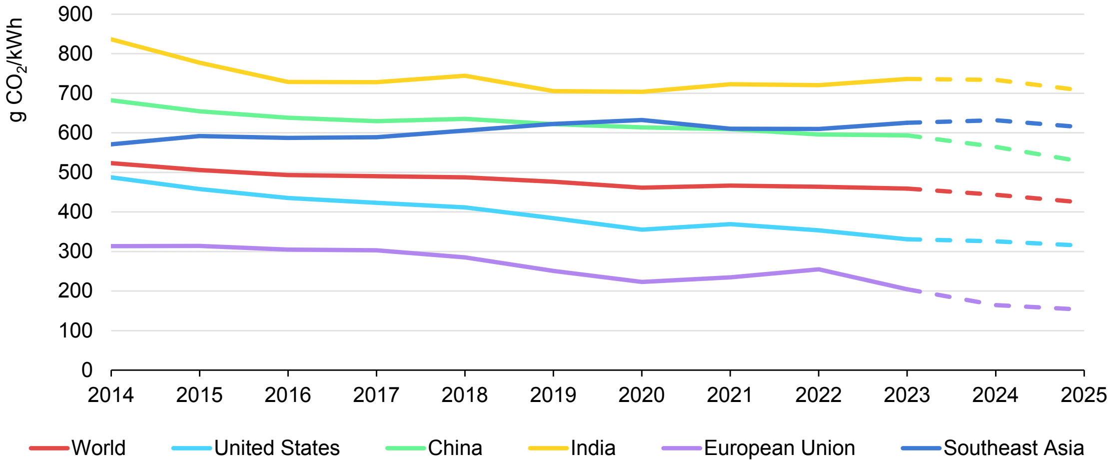
The United States is expected to be one of the few advanced economies in 2024 where power sector emissions increase year-on-year, rising by slightly below 2%. This uptick in emissions follows a sharp decline of 8% in 2023, and is due to a year-on-year increase in coal-fired-generation, driven by rebounding electricity demand from the 2023 decline and gas price dynamics. These trends will be sensitive to weather impacts and market prices for natural gas in the second half of the year.

Changes in global CO_2 emissions from electricity generation, 2025 vs. 2023



With an increasing share of low-emissions sources, emission intensity of the world's power generation is set to decrease by an annual average rate of 4% from 460 g CO_2/kWh in 2023 to 425 g CO_2/kWh in 2025. The European Union is expected to see the highest rate of decline in emissions intensity, with an average annual reduction of 13%, from 205 g CO_2/kWh in 2023 to 155 g CO_2/kWh in 2025. China is also expected to see a strong decline (6% on average), from 595 g CO_2/kWh in 2023 to 525 g CO_2/kWh in 2025.

CO_2 intensity of electricity generation in selected regions, 2014-2025



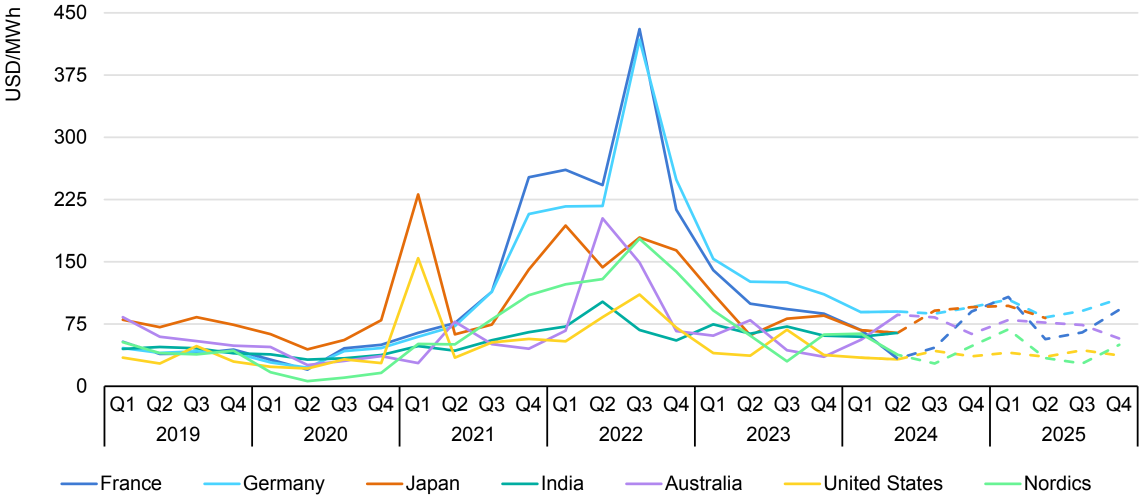
Note: The CO_2 intensity is calculated as total CO_2 emissions divided by total generation.

Prices: Wholesale electricity prices continue to diverge across regions

Energy commodity markets experienced a slight easing in the first half of 2024 compared to 2023. This put downward pressure on wholesale electricity prices in many markets compared to the previous year, a trend that was also supported by robust generation from renewables in certain regions. While average wholesale prices returned to their pre-2021 levels in some markets, they remain elevated in others. The intense heatwaves many regions are currently experiencing may put upward pressure on prices in the summer due to increased electricity demand for cooling.

Gas drives electricity prices higher in Europe, while US markets remain stable on average

Quarterly average wholesale prices for selected regions, 2019-2025



Notes: The prices for Australia and the United States are calculated as the demand-weighted average of the available prices of their regional markets. Continuous lines show historical data and dashed lines refer to forward prices.

Sources: IEA analysis based on data from RTE (France) – accessed via the ENTSO-E Transparency Platform; Bundesnetzagentur (2024), SMARD.de; AEMO (2024), Aggregated price and demand data; EIA (2024), Short-Term Energy Outlook, July 2024; IEX (2023), Area Prices; EEX (2024), Power Futures; ASX (2024), Electricity Futures © ASX Limited ABN 98 008 624 691 (ASX) 2020. All rights reserved. This material is reproduced with the permission of ASX. This material should not be reproduced, stored in a retrieval system or transmitted in any form whether in whole or in part without the prior written permission of ASX. Latest update: 11 July 2024.

In many **European** countries, including France and Germany, wholesale electricity prices continued to decline in H1 2024. The average price in Europe was around USD 70/MWh, falling back to the H1 2021 level but remaining 40% above the H1 2019 average.

French prices in H1 2024 were further reduced by low seasonal electricity consumption and generation oversupply. The previously tight electricity market in France has eased as output from nuclear power plants continued to rise, the backbone of the country's electricity generation. Since mid-March 2024, the cross-zonal transmission was restricted due to safety concerns. With limited import/export availability, this has partly isolated domestic wholesale prices. Prices in France were on average about USD 55/MWh lower than in Germany in Q2 2024. While futures prices indicate an expectation that the wholesale price spread shrinks, they also suggest higher prices in Germany than in France. The price spread between the two markets shrinks even more for winter delivery periods due to higher electricity demand during winter and elevated prices for natural gas, which more frequently sets the market prices as the marginal fuel.

In the **United States**, wholesale electricity price averaged in H1 2024 around USD 30/MWh, down almost 15% compared to the same 2023 period. Prices in the first six months of year reached levels last seen in H1 2019. Despite experiencing a mild winter on average, the United States faced short-term extreme weather conditions and spikes in electricity prices in some states such as New York and the New England region due to the freezing of natural gas wells in early 2024. Over the outlook period, forward prices for 2024 and 2025 indicate a stable price level, with comparatively higher summer prices (Q3 2024) that are mainly driven by expectations of elevated electricity demand in the summer in many US regions due to heatwaves.

Japanese wholesale prices saw a 35% y-o-y decline in H1 2024, averaging below USD 70/MWh in Q2 2024. The drop was driven by lower LNG prices, a mild winter and a gradual restart of the nuclear power fleet. Futures indicate an increase in wholesale electricity prices towards the upcoming 2024/25 winter, with a price level around USD 90/MWh, driven by higher gas futures prices.

Wholesale electricity prices in **Australia** in H1 2024 remained similar to the same period during the prior year, at an average level of around USD 70/MWh. Primarily driven by stable coal prices and increasing renewable energy sources (RES) capacity, wholesale electricity prices remained stable even though Australia saw growth in electricity demand and occasional extreme weather conditions. In mid-February 2024, Victoria experienced a severe storm causing a power outage, which led to price spikes. Electricity futures indicate a relatively stable price level but with troughs in the fourth quarter in both 2024 and 2025.

In **India**, electricity prices saw a 10% y-o-y decline during the first half of 2024. Proactive measures taken by the government and regulators, including the sale of surplus requisitioned electricity on power exchanges, increased fuel supply and ensured higher availability of generating units, creating greater liquidity on the exchanges, which put downward pressure on prices. However, prices remained 40% above the 2019 average, supported by surging electricity demand driven by economic growth and rising cooling needs.

Negative electricity prices are becoming increasingly common in some regions

Even though negative prices are still uncommon in many power markets, there has been a significant increase in 2024 in the frequency of negative wholesale price events in various regions. In some markets, such as South Australia, hours with negative prices seem to have become almost the new normal, with a share of around 20% since 2023. In some other markets like Southern California and in parts of Texas a share of negative prices above 5% have also become common.

The phenomenon of negative prices is not exclusive to electricity markets, but they are much more common due to its characteristics. In electricity markets, supply and demand must be continuously balanced in the face of limited storage capacity and insufficient flexibility on the demand side, while at the same time certain sources of generation are subject to technical, economic, contractual or regulatory constraints. This can lead to situations where someone is willing to pay someone else to take their energy instead of shutting down production. In this sense, negative prices are an important market signal that encourages all those in a position to do so to reduce production and increase consumption.

There can be multiple factors that contribute to negative prices. Support schemes for renewable generation, for example, in the form of feed-in-tariffs and certificates of origin, or other contractual arrangements incentivising that the sent-out volume must be maximised, can contribute to negative prices. As a result, renewable generators under such schemes may continue to produce despite prices falling below zero. On the other hand, rooftop solar PV modules (or older generation wind turbines) are typically not economically curtailed due to technical limitations, so they are not responsive to price signals.

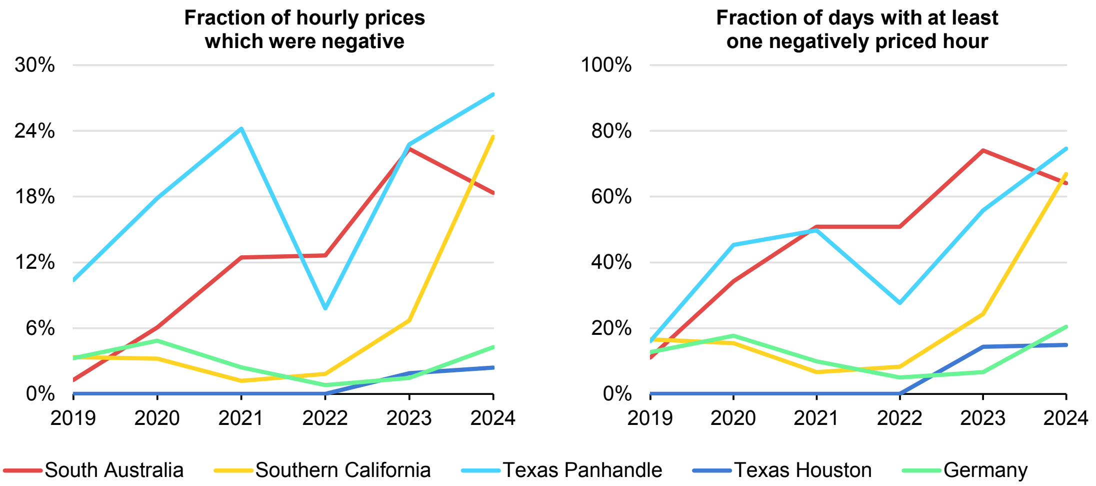
For some thermal power plants shutting down and then restarting later can be slow and costly so they may prefer to pay to stay on during periods of low electricity prices (i.e. lower than their marginal costs). The existence of out-of-market commitments of conventional generators can also play a role, such as some plants running despite negative energy prices in order to provide ancillary services to the system. Grid congestion, or limited availability (or lack of) electricity import and export capacity between balancing areas can further contribute to negative prices.

Negative prices have become the new normal in some markets, while in others the first cases are appearing

A surge in the number of hours with negative prices was a common trend in various markets in H1 2024. In the first half of the year, the share of negative hours in **Southern California** was above 20%, more than tripling from 7% in H1 2023. In April 2024 wholesale prices Southern California and the **Texas Panhandle** area were negative for 40% of the time. In **South Australia**, prices were negative 18% of the time in H1 2024, slightly less than in 2023.

In these regions it is now far more common to have a day with at least some negatively priced intervals than a day with only positive prices. In South Australia, for example, there were only 75 days without any negatively priced hour in the complete year of 2023. The volume-weighted average spot price of inter-region exports from South Australia to Victoria was negative in 2023. This means that, overall, South Australia paid not only to import electricity but also to export it.

Negative wholesale price trends in select regions in the first half of the year, 2019-2024



Note: Southern California corresponds to the SP15 area.

In **Europe**, the record for maximum duration of a negative price event was broken in 16 countries, including Sweden, Finland, Estonia, Latvia, Lithuania, the Netherlands, Poland and Slovenia. Several bidding zones of Norway experienced Europe's longest ever negative price event of 44 hours in 19-21 September 2023, driven by an abundance of hydropower generation at a period when high solar and wind in Continental Europe limited export opportunities.

Spain experienced its first ever negative price on the day-ahead market in April 2024, following the implementation of updated Rules on the operation of electricity markets in December 2023, which permitted negative prices in alignment with

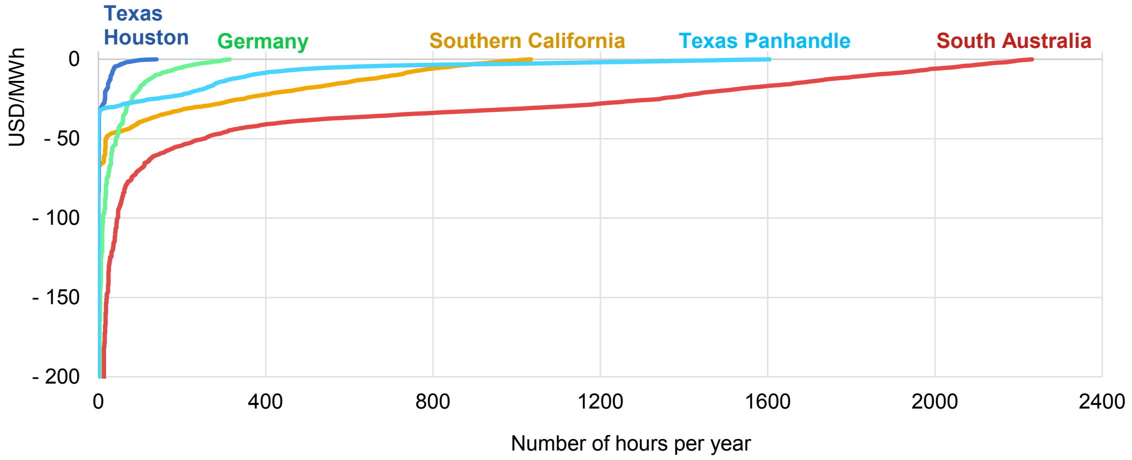
European regulations. In **Japan**, the lowest price allowed is JPY 0.1/kWh. Similarly, in **New Zealand** the minimum allowed bid is NZD 0.01/MWh, however a review of their market design in December 2023 recommended changing the rules to allow negative prices.

Negative prices have so far been in a moderate range, with extremely low prices occurring rarely

Despite the increasing frequency of negative price events, the vast majority are only slightly below zero. Following the guidance decision from the EU regulator ACER in January 2023, the minimum clearing prices for day-ahead markets across Europe have been standardised at EUR -500/MWh. However, extremely negative prices are still rare. Over the 12-month period ending in May 2024, the price in the Netherlands was negative for 377 hours. It hit the floor price of EUR -500/MWh for only 3 hours, compared to 239 hours between EUR -10/MWh and EUR 0/MWh. In Germany the hourly price fell as low as EUR -258/MWh, but almost 80% of negative prices were above EUR -15/MWh.

In Australia the minimum allowed price is AUD -1 000/MWh (USD -665/MWh). This was reached for 26 hours in South Australia in 2019, and 21 hours in Queensland in 2021, but for less than 1 hour in each region in the 12-month period ending in May 2024. In Texas there were 29 negatively priced hours, some as low as USD -84/MWh, but about 70% were above USD -3/MWh.

Duration curves for negative prices in selected regions, June 2023 to May 2024



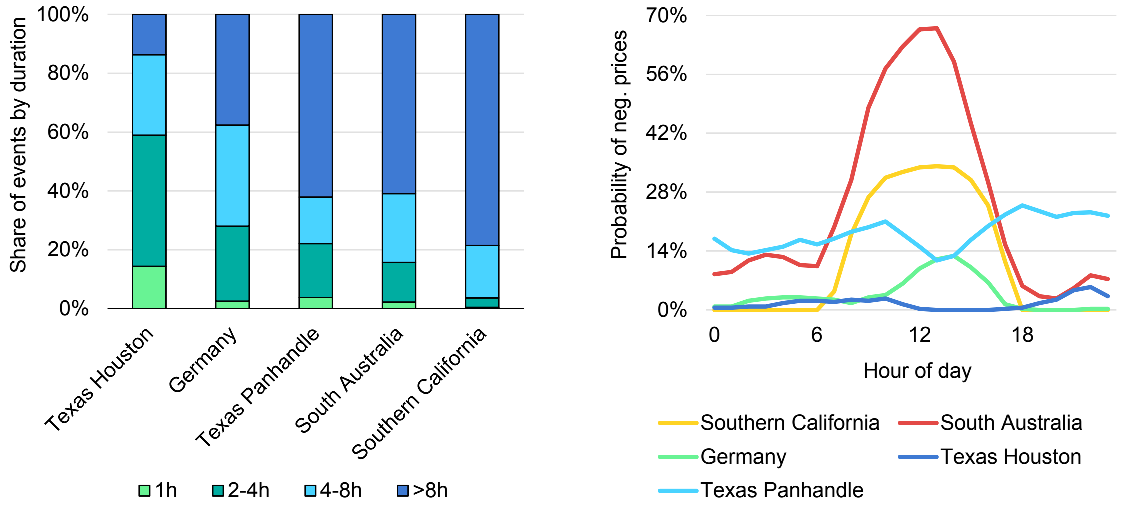
Notes: Southern California corresponds to the SP15 area. The minimum observed prices were USD -67/MWh for Southern California, USD -84/MWh for Texas Houston, USD -36/MWh for Texas Panhandle, AUD -370/MWh (hourly average) for South Australia, and EUR -258/MWh for Germany. Note that the values are plotted in the figure in USD/MWh.

Negative prices commonly occur during sunlight hours, while solar PV increasingly faces price cannibalisation

The likelihood of negative prices is higher during daytime in many regions, such as South Australia, California and Germany. This is driven by the increasing share of solar PV generation that is not fully market-integrated, which faces a not sufficiently price-responsive demand side as well as limited energy storage. In South Australia, for example, where solar PV accounts for almost 20% of total electricity generation, the probability of having negative prices over the period June 2023-May 2024 was above 60% around noon hours. In Southern California, with a similarly high solar PV share in generation, this probability was above 30% at noon.

The duration of negative price events also tends to increase when there is a higher solar PV share in supply. In Southern California, from June 2023 to May 2024, 80% of the total negative price events with consecutive prices below zero had a duration of more than 8 hours. This share was 60% in South Australia and 40% in Germany.

Share of negative price events by duration (left), and probability of negative prices over a day (right) in selected regions, June 2023 to May 2024

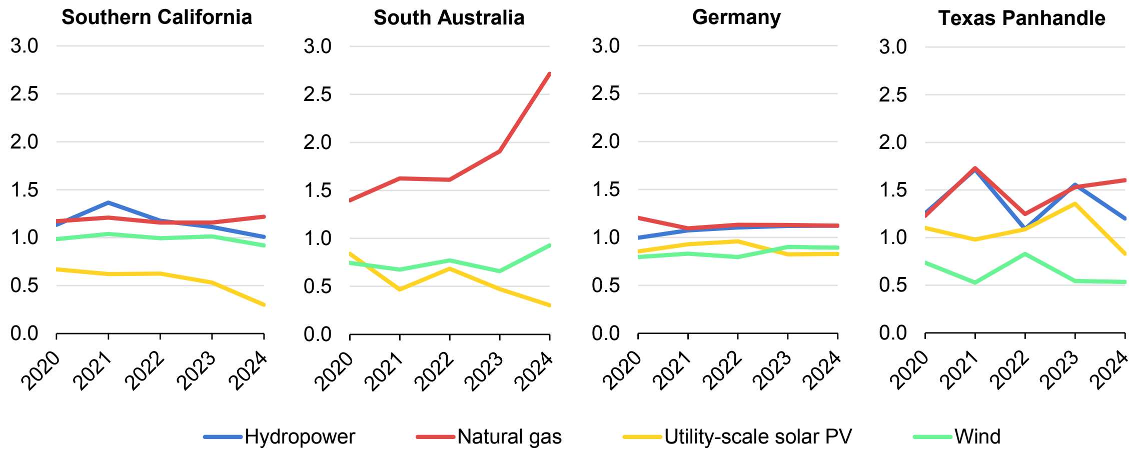


Notes: For the analysis on the left, each time the price went negative, the time elapsed until it returned above USD 0/MWh was counted. Two negative price events separated by a single positively-priced interval are counted as separate events. Percentages are based on the total number of hours where the price was negative. Prices in sub-hour markets were aggregated to hourly prices. Southern California corresponds to the SP15 area.

In Texas, where the overall share of solar PV in total generation is below 10%, negative price durations in the Houston area generally lasted between 2-4 hours and occurred outside the midday peak in the morning and evening hours. By contrast, in the Panhandle region with a high share of wind energy in electricity generation but limited electricity export capacities to other regions, the majority of negative price events lasted longer than 8 hours.

The trends of higher frequency of negative prices during daytime and the reduced system value of solar PV commonly go hand in hand in many regions. In markets where solar PV's share in generation has been increasing rapidly, such as South Australia, Germany, the Netherlands and Spain, the price 'captured' by utility-scale solar has declined over the last few years. Prior to 2019, the capture rate[1] of solar PV in these regions was generally greater than 1, indicating that the output coincided with higher priced periods. However, as installed capacity continued to increase, this favourable position deteriorated due to the so-called 'cannibalisation' effect. The decline is less pronounced for wind, since its speed is more localised than sunlight, and wind generators can produce more during evening demand peaks. By contrast, for dispatchable sources such as hydropower and natural gas-fired plants the capture rates have remained more robust, and in the case of South Australia, increased substantially in recent years.

Capture rate of generators by fuel type in selected regions during the first half of the year, 2020-2024



Notes: Capture rate is a measure of how well a generator (or set of generators) performed, relative to the overall market. A rate less than 1 suggests the generator is generating mostly during low prices. A rate above 1 suggests a generator's output coincides with higher priced periods. Southern California corresponds to the SP15 area.

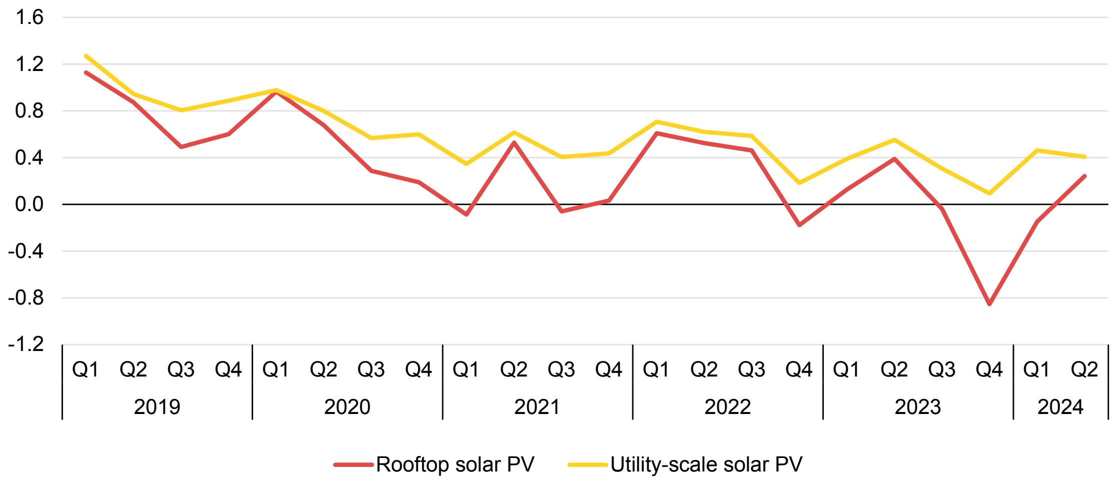
[1] Capture rate is a measure of how well a generator (or set of generators) performed in terms of timing generation to align with high prices. Capture rate is the volume-weighted average price of a generator (or set of generators) divided by the (unweighted) average price of the region. Phrased differently, it is the total spot revenue for a generator(s) (USD) divided by total volume (MWh) to get USD/MWh, divided by average price (also USD/MWh). If a generator produced a constant power output for the whole time period, the capture rate would be 1. Peaking plants turn on for high-priced periods and off for low periods, so they tend to have capture rates above 1. A rate less than 1 suggests a generator is generating mostly during low prices.

Inflexible rooftop solar PV is contributing to negative prices and reduced solar capture rates

In many regions which are seeing large number of hours with negative prices, inflexible rooftop solar PV generation is a significant contributor to negative prices and reduced solar capture rates. In numerous markets in the world, grid-scale solar tends to be actively managed which enables economic curtailment when spot prices go negative. If a generator turns off whenever prices are negative, their capture rate cannot drop below zero. However, many rooftop solar installations generate at maximum capacity regardless of whether the spot price is negative, resulting in reduced solar capture rates. This is commonly due to technical limitations in curtailing rooftop solar PV generation (e.g. unobservable and uncontrollable distributed generators). In cases where curtailment is technically possible, these are generally incentivised to continue producing due to support schemes such as net metering, certificates and feed-in-tariffs, among other initiatives.

In South Australia, for example, the capture rate for rooftop solar has actually dropped below zero for some quarters. This means that for over a period of several months, rooftop solar PV cost retailers more money on the spot market for generation during negative-priced periods than they earned from the remaining generation, though the solar panels may still be earning money overall once other revenue streams such as feed-in-tariffs and Small-scale Technology Certificates (STCs) are accounted for.

Solar capture rates in South Australia, 2019-2024



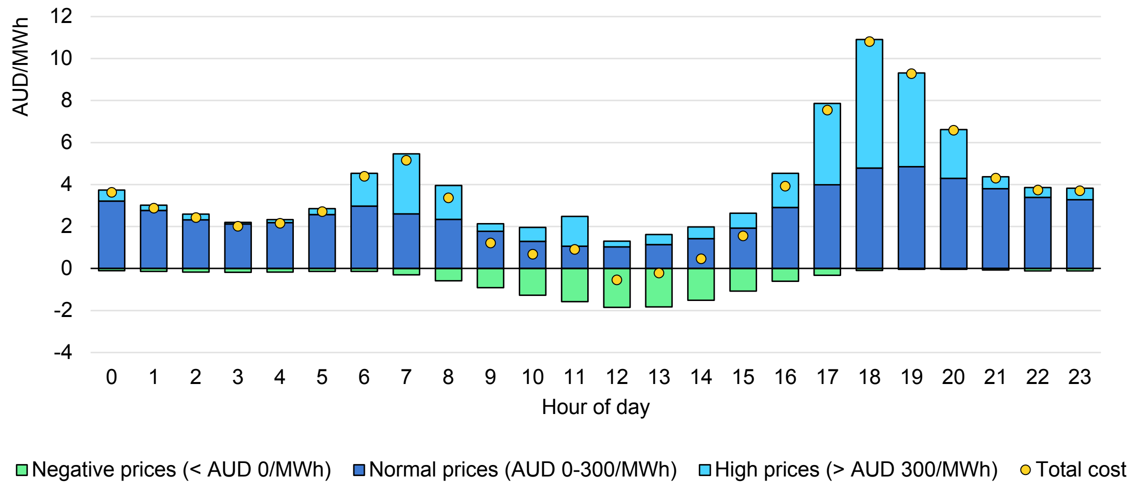
Notes: Capture rate is a measure of how well a generator (or set of generators) performed, relative to the overall market. A rate less than 1 suggests the generator is generating mostly during low prices. A rate above 1 suggests a generator's output coincides with higher priced periods. A negative capture rate means that a generator incurred more cost for generating during negative prices than the revenue they earned from generating during positive prices. This excludes revenue from feed-in-tariffs, and small-scale renewable generation certificates (certificates of origin).

To remedy the inflexibility, some markets require that new rooftop solar panels are able to be remotely disconnected. In many cases, this is often for system strength reasons though, not economic ones. To increase the overall system value, support schemes can be designed to incentivise price-responsive generation. In addition, instead of the typical South-North orientation that aims to maximise generation and revenues, opting for East-West orientation can also be incentivised in markets with reduced solar capture rates.

More negative prices do not necessarily correspond to lower overall electricity prices

Negative prices tend to occur when electricity demand is quite low. Therefore, the total volume of energy traded at negative prices is rather limited, even when the corresponding fraction of time with negative prices is high. Moreover, very low negative prices are quite rare, and most of the negative prices are only slightly below zero. As a result, the impact of negative prices on the overall wholesale electricity cost is small. Nevertheless, consumers which have direct access to wholesale prices, such as large energy consumers in the industry and services sectors, can benefit from negative prices via shifting consumption.

Hourly average cost of electricity on the wholesale market in South Australia, June 2023 to May 2024



Notes: Each period was classified based on whether the spot price was negative, or high (above AUD 300/MWh) or in between. Generated volume was multiplied by the spot market price each period to calculate generation-weighted averages.

In the case of retail prices with fixed tariffs, the effect is less straightforward. Whilst negative prices tend to reduce the overall wholesale component of retail bills, this can be cancelled out by an increase in levies that consumers pay to support the renewable subsidy schemes. This is because these generators in the subsidy schemes would need to recover the cost of generating during negative periods via increased surcharges in retail bills or from the state budget (financed via taxpayers). Negative price periods are also generally associated with higher balancing costs. This in turn would commonly be reflected in consumers' bills, such as in the form of a higher grid cost component.

On the other hand, negative prices can reduce consumers' electricity costs with flexible consumption under appropriate tariff structures. Consumers with time-of-use tariffs can benefit from lower prices and reduce their energy bills via shifting their consumption from high-price periods to low-price periods (e.g. charging their electric vehicles during noon when prices are more likely to be low or negative). With smart meters becoming more widespread in many markets around the world, appropriate tariff design can help ensure that retail consumption is more price responsive and better aligned with system needs.

Negative prices provide price signals for more flexibility, especially for storage and demand response

Negative pricing sends a crucial market signal for flexible supply and demand, including storage, which should be enabled through appropriate market rules for incorporation into the power system. In this context, negative prices can provide incentives for generators to become more flexible in order to avoid losing money and for the consumers to invest in technologies to increase or shift their consumption. Negative prices can also provide market signals to invest in storage, through increasing arbitrage opportunities. In South Australia in Q4 2023, batteries (overall) received more money for charging during negatively price periods than they paid to charge during positively-priced periods. The prevalence of negative prices in South Australia has transformed charging from a source of cost for those batteries into a revenue stream.

While negative prices can incentivise investments in flexibility, they may not be enough on their own. Appropriate regulatory frameworks and market design, as well as updated tariff structures to ensure fair competition between different flexibility options, will be important to allow for uptake in flexibility solutions. Increasing digitalisation and aggregating demand flexibility via virtual power plants are further means of making demand more price responsive. Time-of-use tariffs and smart charging of electric vehicles are important factors that would contribute to greater flexibility on the demand side. Building out grids to resolve congestion issues and improving interconnections with other balancing areas to unlock the flexibility in these systems will also be crucial for increasing the system flexibility.

General annex

Summary tables

Regional breakdown of electricity demand, 2022-2025

TWh	2022	2023	2024	2025	Growth rate 2022-2023	Growth rate 2023-2024	Growth rate 2024-2025
Africa	755	769	800	839	1.8%	4.0%	4.9%
Americas	6 370	6 326	6 523	6 667	-0.7%	3.1%	2.2%
of which United States	4 332	4 262	4 392	4 475	-1.6%	3.0%	1.9%
Asia Pacific	13 869	14 612	15 435	16 273	5.4%	5.6%	5.4%
of which China	8 678	9 283	9 882	10 498	7.0%	6.5%	6.2%
Eurasia	1 328	1 348	1 369	1 390	1.5%	1.6%	1.5%
Europe	3 682	3 596	3 667	3 762	-2.3%	2.0%	2.6%
of which European Union	2 663	2 578	2 623	2 692	-3.2%	1.7%	2.6%
Middle East	1 228	1 257	1 292	1 335	2.3%	2.8%	3.3%
World	27 233	27 907	29 085	30 267	2.5%	4.2%	4.1%

Notes: Data for 2023 are preliminary; 2024-2025 are forecasts. Differences in totals are due to rounding.

Breakdown of global electricity supply, 2022-2025

TWh	2022	2023	2024	2025	Growth rate 2022-2023	Growth rate 2023-2024	Growth rate 2024-2025
Nuclear	2 685	2 761	2 805	2 903	2.8%	1.6%	3.5%
Coal	10 485	10 689	10 771	10 693	1.9%	0.8%	-0.7%
Gas	6 512	6 576	6 652	6 690	1.0%	1.2%	0.6%
Other non-renewables	906	840	779	730	-7.3%	-7.2%	-6.4%
Total renewables	8 531	8 958	10 017	11 218	5.0%	11.8%	12.0%

Notes: Data for 2023 are preliminary; 2024-2025 are forecasts. Differences in totals are due to rounding. Unless otherwise specified, generation numbers refer to gross generation.

Global CO_2 emissions from power generation, 2022-2025

Mt CO_2	2022	2023	2024	2025	Growth rate 2022-2023	Growth rate 2023-2024	Growth rate 2024-2025
Total emissions	13 500	13 684	13 754	13 663	1.4%	0.5%	-0.7%

Regional and country groupings

Africa – Algeria, Angola, Benin, Botswana, Cameroon, Congo, Democratic Republic of the Congo, Côte d'Ivoire, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Libya, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, South Sudan, Sudan, United Republic of Tanzania, Togo, Tunisia, Zambia, Zimbabwe and other African countries and territories.[1]

Asia – Bangladesh, Brunei Darussalam, Cambodia, Chinese Taipei, India, Indonesia, Japan, Korea, Democratic People's Republic of Korea, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, People's Republic of China,[2] Philippines, Singapore, Sri Lanka, Thailand, Viet Nam and other Asian countries, territories and economies.[3]

Asia Pacific – Australia, Bangladesh, Brunei Darussalam, Cambodia, Chinese Taipei, India, Indonesia, Japan, Korea, Democratic People's Republic of Korea, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Nepal, New Zealand, Pakistan, People's Republic of China,[2] Philippines, Singapore, Sri Lanka, Thailand, Viet Nam and other Asian countries, territories and economies.[4]

Central and South America – Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Curaçao, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Venezuela and other Latin American countries and territories.[5]

Eurasia – Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Russian Federation, Tajikistan, Turkmenistan and Uzbekistan.

Europe – Albania, Austria, Belgium, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus,[6,7] Czech Republic, Denmark, Estonia, Finland, France, Germany, Gibraltar, Greece, Hungary, Iceland, Ireland, Italy, Kosovo[8] Latvia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Republic of Moldova, Romania, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Republic of Türkiye, Ukraine and United Kingdom.

European Union – Austria, Belgium, Bulgaria, Croatia, Cyprus,[6,7] Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain and Sweden.

Middle East – Bahrain, Islamic Republic of Iran, Iraq, Israel[9], Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, the United Arab Emirates and Yemen.

Nordics – Denmark, Finland, Norway, Sweden

North Africa – Algeria, Egypt, Libya, Morocco and Tunisia.

North America – Canada, Mexico and the United States.

Southeast Asia – Brunei Darussalam, Cambodia, Indonesia, Lao, People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. These countries are all members of the Association of Southeast Asian Nations (ASEAN).

Advanced economies – OECD member nations, plus Bulgaria, Croatia, Cyprus, Malta and Romania.

Emerging markets and developing economies – All other countries not included in the advanced economies regional grouping.

[1] Individual data are not available and are estimated in aggregate for: Burkina Faso, Burundi, Cape Verde, Central African Republic, Chad, Comoros, Djibouti, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Reunion, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone, Somalia, Eswatini and Uganda.
[2] Including Hong Kong.
[3] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Macau (China), Maldives and Timor-Leste.
[4] Individual data are not available and are estimated in aggregate for: Afghanistan, Bhutan, Cook Islands, Fiji, French Polynesia, Kiribati, Macau (China), Maldives, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga and Vanuatu.
[5] Individual data are not available and are estimated in aggregate for: Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands (Malvinas), Grenada, Guyana, Montserrat, Saba, Saint Eustatius, Saint Kitts and Nevis, Saint Lucia, Saint Pierre and Miquelon, Saint Vincent and the Grenadines, Sint Maarten, and the Turks and Caicos Islands.
[6] Note by Türkiye: The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Türkiye recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Türkiye shall preserve its position concerning the "Cyprus issue".
[7] Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Türkiye. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.
[8] The designation is without prejudice to positions on status and is in line with the United Nations Security Council Resolution 1244/99 and the Advisory Opinion of the International Court of Justice on Kosovo's declaration of Independence.
[9] The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD and/or the IEA is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Abbreviations and acronyms

AEMO	Australian Energy Market Operator
AI	artificial intelligence
AWS	Amazon Web Services
BNetzA	Bundesnetzagentur – German Federal Network Agency
CAGR	compound annual growth rates
EAF	electric arc furnace
ERCOT	Electric Reliability Council of Texas
EU	European Union
EV	electric vehicle
GDP	gross domestic product
GPUs	graphics processing units
IEA	International Energy Agency
IMF	International Monetary Fund
PPA	power purchase agreements
PUE	Power Usage Effectiveness
PV	photovoltaic
RES	renewable energy sources
STCs	Small-scale Technology Certificates
SMR	small modular reactors
USD	United States Dollar
VRE	variable renewable energy

Units of measure

g CO_2	gramme of carbon dioxide
g CO_2/kWh	gramme of carbon dioxide per kilowatt hour
GW	gigawatt
kW	kilowatt
MW	megawatt
MWh	megawatt-hour
Mt/yr	million tonnes per year
Mt CO_2	million tonnes of carbon dioxide
Mt CO_2/yr	million tonnes of carbon dioxide per year
GW	gigawatt
GWh	gigawatt hour
TWh	terawatt-hour

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